AD-780 236

EMP SIMULATORS FOR MISSILES AND AIRPLANES

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EG and G, Incorporated

Prepared for:

Naval Ordnance Laboratory

4 February 1974

EG&G

AL-1026
4 FEBRUARY 1974

AD780236

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PREPARED FOR

NAVAL ORDNANCE LABORATORY
WHITE OAK
SILVER SPRING, MARYLAND 20910

UNDER NOL CONTRACT
N60921-73-C-0033
AND
MRC SUBCONTRACT 3-1005

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ABSTRACT

This manual is intended as a guide to EMP Simulator selection. Descriptions of EMP Simulators were collected from a large number of documents and up-dated. Detailed technical discussions of 16 operating simulators are given along with cost and schedule information. Cost estimates for the construction of various types of simulators are also provided. Technical and financial information is summarized in table form for quick reference. A general discussion of the EM criterion pulse and EMP simulation is included as an aid for evaluating simulator performance.

PREFACE

The objectives of this study were twofold: first, to provide a comprehensive, useful reference handbook on existing EMP simulators to which a test planner could refer to determine the feasibility of using an existing simulator for his program; second, to provide approximate but reasonable estimates of costs of developing a new simulator in order to determine if this would be more advantageous to a potential user of a facility. The scope and depth of the work were limited by the short time and funds available. Consequently, the treatment of existing simulators is more complete than the discussions and the estimates of cost for new simulators.

The chapter on existing simulators is thought to be complete; however, the reader is given recommended sources of more detailed information on the design, schedules, costs, etc. for these simulators.

The cost estimates associated with building a new simulator are very general and approximate. They are based on past EG&G experience with simulation development programs. They are not based on a detailed design and costing of a particular simulator design. Secondly, the costs of a particular simulator can vary dramatically (factors of 2 or more), depending upon the details of the design and the degree of sophistication in the instrumentation and support systems required. The chapter on new simulators was included as a guide for making trade-off decisions between using an existing simulator or developing a new simulator. EG&G recommends that once specific simulator design requirements are identified along with a specific test object, a detailed design study and costing analysis be performed to accurately determine the trade-offs involved.

The data on existing simulators were obtained from available reference books, reports, borchures, and discussions with personnel involved in their construction and operation. The EMPRESS discussion was prepared by Mr. William C. Emberson of NOL.

Chapter 2, EMP Testing Overview, is based on a draft prepared by Mr. Edmund Pace of MRC.

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CHAPTER 1
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1.1 INTRODUCTION

This manual was produced with two objectives in mind. First, it is intended to serve as a quick reference for EMP test planners who wish to determine which of the many operational EMP simulators would be most appropriate for a particular test program. The discussions are geared mainly toward pulse testing of missiles and airplanes; however, the information should be useful to those who are interested in testing other objects as well.

The matrix in the next section of this chapter summarizes the important financial and electromagnetic characteristics of existing simulators in table form and lists the expected performances of the simulator for testing objects of various sizes ranging from a 3 meter missile to a C-130 airplane.

Diagrams and technical discussions of the various facilities, culled from a large number of documents, are presented in Chapter 3. Whenever available, information regarding rental costs and scheduling of the simulators is included.

Secondly, this document should serve as a guide for test planners who may, for reasons of economy or scheduling, desire to build a new simulator. Chapter 4 provides, in table form, construction cost estimates for a variety of simulators. Costs for both temporary and permanent facilities are given. Chapter 4 also breaks down each type of facility into its components and lists the cost of each component so that a good cost estimate of any potential simulator, however simple or elaborate, can be obtained. Cost estimates for bounded array and radiating CW systems are provided. All construction cost estimates are based on EG&G's broad experience in simulator construction. The cost estimates for new simulators are summarized in the next section of this chapter.

Finally, much of the information contained in this compendium, especially that regarding simulator rental costs and schedules, was obtained from the facilities' sponsoring agencies and cannot be found in any of the numerous EMP handbooks. The tables and discussions should serve as an accurate and up-to-date guide for EMP test planning.

1.2 SUMMARY

The information developed in detail in Chapters 3 and 4 is summarized in table form in this section in order to provide a handy reference guide. Explanations of the data can be found in the following chapters.

Table 1-1 summarizes the important technical and financial details of existing simulators. The matrix is intended to be used as a quick reference and as a guide for the selection of simulators for EMP test programs. In most cases, the table should provide enough information to reduce the selection of a simulator to two or three possibilities. More detailed information can then be found in the discussions of Chapter 3 and in the references given at the end of each discussion.

The matrix examines the suitability of each simulator for testing four different sizes of test objects:

1) a 3m missile
2) a 10m missile (Poseidon)
3) an A-6 sized airplane: 18.1m x 4.95m x 16.5m (wing span)
4) a C-130 sized airplane: 29.78m x 11.6m x 40.25m (wing span)

For some simulators, the test volume is too small to accommodate the larger test objects; accordingly, "UNUSABLE" is written in the column for field uniformity. The only parameters that vary markedly with test object size are field uniformity and peak field strength. For the radiating simulators, these two parameters are closely related. For example, by

Table 1-1 Simulator Characteristics

PARAMETER / SIMULATOR	BASIC PULSER VOLTAGE	FIELD POLARIZATION	PEAK FIELD STRENGTH	FIELD UNIFORMITY 3M MISSILE	FIELD UNIFORMITY 10M MISSILE	FIELD UNIFORMITY A6	FIELD UNIFORMITY C-130	RISETIME 10%–90%	FIXED/TRANSPORTABLE	DATA ACQUISITION CAPABILITY	DATE AVAILABLE	SPONSORING AGENCY	O & M COSTS	ORIGINAL COST MILLIONS	RECONSTRUCTION COST	C W CAPABILITY
BOUNDED ARRAYS																
ALECS	2.2 MV	V (1)	100 kV/m	EXCELLENT	EXCELLENT	UNUSABLE	UNUSABLE	6–8ns	F	EXCELLENT	EARLY '75	AFWL	15K PER MONTH	2.5	1–1.5 M	YES
ARES	3.7 MV	V (1)	82.5 kV/m	BETTER THAN ± 20%	BETTER THAN ± 20%	± 20%	POOR	6ns	F	EXCELLENT	MID '75	DNA	2–2.5K PER DAY	~ 7	5–7 M	NO
TRESTLE	H: 10MV V: 4MV	AND V (2)	H: 100 kV/m V: 50 kV/m	BETTER THAN ± 20%	BETTER THAN ± 20%	± 20%	± 20%	20ns	F	EXCELLENT	H: 1/78 V: 3/78	AFWL	125K PER MONTH	~ 25	25 M	YES
TEFS	100 KV	H OR V	66 kV/m	EXCELLENT	EXCELLENT	GOOD	UNUSABLE	15–20ns (15)	T	MODERATE	IMMED	HDL	40K PER MONTH	~ 2	1–1.5 M	YES
HEMPS	100 KV	V (1)	80 kV/m	EXCELLENT	GOOD	GOOD	UNUSABLE	10ns	F	EXCELLENT		SAFCA	15K PER WEEK			NO
VERTICALLY POLARIZED RADIATORS																
VPD	1.8 MV	V (1)	6 kV/m AT 60m	(17)	(17)	(17)	~ ± 30% (10)	5 ns	F	EXCELLENT	7/75	AFWL	10K PER MONTH	.4	.4	NO
DRI	1.4 MV	V (3)	500 kV/m AT 1M	EXCELLENT (17)	EXCELLENT (17)	GOOD (4)	GOOD (4)	1 ns	F (5)	POOR	2/74	DRI				NO
LASL (6)	240 KV	V	100 V/m AT 1 MILE	EXCELLENT	EXCELLENT	EXCELLENT	EXCELLENT	1 ns (7)	F	MODERATE		LASL			80–100K	NO
EMPRESS	2.5 MV	V	24 kV/m AT 50 M	EXCELLANT	GOOD	GOOD	GOOD	8-13ns	F	MODERATE	IMMED	NOL	4K PER WEEK	0.5 (21)	0.3 (21)	NO
HORIZONTALLY POLARIZED RADIATORS—OR HYBRIDS																
LASL (6)	120 KV	H	15 V/m AT 1 MILE	EXCELLENT	EXCELLENT	EXCELLENT	EXCELLENT	1 ns (7)	F	MODERATE	EARLY '74	LASL			80–100K	NO
HPD	5 M OR 1.0 MV	H	25 kV/m AT M	EXCELLENT (19)	GOOD	POOR	POOR	4 ns	F	EXCELLENT	7/74	AFWL	10K PER MONTH	1.6 (16)	1.3	NO
SUSPENDED RES	1.8 MV	H	7 kV/m AT 54 M	(9) (8)	(8)	(8)	(8)	5 ns	F	EXCELLENT	IMMED	AFWL	4K PER WEEK (9)			NO
TORUS	2.5 MV	H, V (14)	50 Kv/m	EXCELLENT	GOOD	GOOD	GOOD	10 ns	T	EXCELLENT	'79	SAMSO				NO
EMPRESS	2.5 MV	H	11 kV/m AT 50 m	EXCELLENT	GOOD	GOOD	GOOD	4 ns	F	MODERATE	IMMED	NOL	4 K PER WEEK	0.5 (21)	0.3 (21)	NO
TEMPS I	4.1 MV	H	52 kV/m AT 50 m	BETTER THAN ±10%	BETTER THAN ± 10%	±10%	± 10%	8 ns	T	EXCELLENT	LATE '75	DNA	1–1.5M PER YEAR			NO
TEMPS II	4.1 MV	H	52 kV/m AT 50m	BETTER THAN ±10%	BETTER THAN ± 10%	±10%	± 10%	8 ns	F	EXCELLENT	2/74 (11)	HDL	(11)			NO
MARTIN MARIETTA LONGWIRE	290 KV	H	1100 V/m AT M	EXCELLENT (19)	EXCELLENT	POOR	POOR (12)	5–20 ns (VARIABLE)	F	EXCELLENT	IMMED	MARTIN MARIETTA				NO
SANDIA LONGWIRE	30 KV	H	400 V/m AT M	EXCELLENT (19)	EXCELLENT			9 ns	F	EXCELLENT		SANDIA CORP				NO
RES	1.8 MV	H OR V	900 V/m AT 500m	EXCELLENT	EXCELLENT	±20% (13)	± 20% (13)	4–6 ns	T	NONE	EARLY '74	AFWL	10K PER WEEK			NO

1. For the 3m or 10m test object, all polarizations can be achieved by proper orientation of test object.
2. Two separate simulators (H and V) form the TRESTLE facility.
3. May be reconstructed in horizontal mode for $15,000.
4. 1/r varying fields - good field uniformity attained by placing large test object near perimeter of 363m ground plane - but reduced field strength results.
5. Transportable at high expense.
6. Used for in-flight tests only.
7. Delta function pulse : 1 ns decay time also
8. Field mapping not yet completed
9. For a double shift 5-day week and a crew of 10 (total)
10. Very uniform in horizontal plane but large variations in field strength with height.
11. Available to secondary user on non-interference basis only - possibly at no cost.
12. Varies by a factor of ~3 over the 40 m wingspan of C-130 sized airplane.
13. May be varied by changing pulser - test object distance - this will also affect field strengths.
14. Horizontal, vertical and intermediate polarizations are possible.
15. Risetime can be improved for small TEFS arrays.
16. Includes 800K for large parking pad and tow-way.
17. 1/r varying.
18. For maximum field strength (~60m from source)
19. Field uniformity for all horizontally-polarized radiators is reduced by ground reflections.
20. Risetime increases with distance from the simulator due to ground losses.
21. Total cost for both horizontal and vertical empress.

placing a large test object at a point far away from the radiator, field uniformity over the volume of the object is generally improved--but at the expense of reduced peak field levels. Similarly, for a small test object, good field uniformity can often be obtained by placing the object close to the pulse source where high field levels are present. The optimum configuration must be based on the variation of field strength with distance (generally 1/r for the radiating simulators) and the particular requirements of the test plan.

Tables 1-2 through 1-5 summarize the estimated construction costs for various types of simulators for each of the test vehicles considered. Costs are provided for both temporary and permanent facilities. These costs are given in more detail in Chapter 4, and the reader is encouraged to review the detailed breakdown to determine if the summarized costs actually estimate his particular need or situation. The temporary facility costs are based on a six month test period with minimal instrumentation. The permanent facility costs are based on purchased instrumentation and a five-year life span.

Table 1-2 Three Meter Missile Estimated Simulator Facility Cost Summary

(Costs in Thousands)

Simulator		Site Preparation	Bldgs	Transmission Line	Pulse Generator	Instrumentation	Design & Mgmt	Integration & C/O	Total Costs	Schedule	O&M Cost/Month
Horizontally Polarized Bounded Array	Perm.	-	-	-	-	NOT APPLICABLE	-	-	-	-	-
	Temp.	-	-	-	-		-	-	-	-	-
Vertically Polarized Bounded Array	Perm.	-	-	-	-	NOT APPLICABLE	-	-	-	-	-
	Temp.	12	25	35	50	39	27	12	200	3 Months	15
Vertically Polarized Low Level Radiating Pulse	Perm.	-	-	-	-	NOT APPLICABLE	-	-	-	-	-
	Temp.	10	57	28	110	58	26	18	279	2 Months	15
CW Option for above (add on)					6	29		5	40		
Horizontally Polarized Low Level Radiating Pulse	Perm.	-	-	-	-	NOT APPLICABLE	-	-	-	-	-
	Temp.	-	-	-	-		-	-	-	-	-
CW Option for above (add on)											
Vertically Polarized Portable Radiating CW	Temp.	10	20	23	6	36	7	6	108	3 Months	15

Table 1-3 Ten Meter Missile Estimated Simulator Facility Cost Summary
(Costs in Thousands)

Simulator		Site Preparation	Bldgs	Transmission Line	Pulse Generator	Instrumentation	Design & Mgmt	Integration & C/O	Total Costs	Schedule	O&M Cost/Month
Horizontally Polarized Bounded Array	Perm.	-	-	-	-	NOT APPLICABLE	-	-	-	-	-
	Temp.	-	-	-	-		-	-	-	-	-
Vertically Polarized Bounded Array	Perm.	173	360	135	200	200	250	75	1393	11 mons	15
	Temp.	12	54	100	150	44	100	20	480	4 mons	23
Vertically Polarized Low Level Radiating Pulse	Perm.	-	-	-	-	NOT APPLICABLE	-	-	-	-	-
	Temp	47	202	50	110	63	31	18	521	3 mons	23
CW Option for above (add on)					6	29		5	40		
Horizontally Polarized Low Level Radiating Pulse	Perm.	-	-	-	-	NOT APPLICABLE	-	-	-	-	-
	Temp.	-	-	-	-		-	-	-	-	-
CW Option for above (add on)											
Vertically Polarized Portable Radiating CW	Temp.	10	20	23	6	36	7	6	108	3 mons	23

Table 1-4 A-6 Airplane EMP Test Simulator Facility Estimated Cost Summary
(Costs in Thousands)

Simulator		Site Preparation	Bldgs	Transmission Line	Pulse Generator	Instrumentation	Design & Mgmt	Integration & C/O	Total Costs	Schedule	O&M Cost/Month
Horizontally Polarized Bounded Array	Perm. Temp.	198 12	300 54	140 45	270 220	200 44	300 50	145 20	1553 445	12 mons 4 mons	15 23
Vertically Polarized Bounded Array (9m)	Perm. Temp.	- 12	- 37	- 73	- 75	NOT APPLICABLE 44	- 47	- 20	- 308	3 mons	- 23
Vertically Polarized Low Level Radiating Pulse	Perm. Temp.	- 10	- 57	- 28	- 80	NOT APPLICABLE 58	- 26	- 18	- 249	2 mons	- 23
CW Option for above (add on)					6	29	-	5	40		
Horizontally Polarized Low Level Radiating Pulse	Perm. Temp.	- 52	- 82	- 60	- 110	NOT APPLICABLE 58	- 52	- 18	- 412	3 mons	- 30
CW Option for above (add on)					12	29		5	46		
Vertically Polarized Portable Radiating CW	Temp.	10	20	23	6	36	7	6	108	3 mons	23

Table 1-5 C-130 Airplane EMP Test Simulator Facility Estimated Cost Summary
(Costs in Thousands)

Simulator		Site Preparation	Bldgs	Transmission Line	Pulse Generator	Instrumentation	Design & Mgmt	Integration & C/O	Total Costs	Schedule	O&M Cost/Month
Horizontally Polarized Bounded Array	Perm.	450	785	340	450	355	425	195	3000	18 mons	20
	Temp.	-	-	-	-NOT APPLICABLE		-	-	-		-
Vertically Polarized Bounded Array	Perm.	395	660	145	250	200	295	120	2065	14 mons	20
	Temp.	-	-	-	-NOT APPLICABLE		-	-	-		-
Vertically Polarized Low Level Radiating Pulse	Perm.	-	-	-	-NOT APPLICABLE		-	-	-		-
	Temp.	47	202	50	110	63	31	18	521	3 mons	30
CW Option for above (add on)					36	90		5	131		
Horizontally Polarized Low Level Radiating Pulse	Perm.	-	-	-	-		-	-	-		-
	Temp.	52	82	60	110	58	32	18	412	3 mons	35
CW Option for above (add on)					12	29		5	46		
Vertically Polarized Portable Radiating CW	Temp.	10	20	23	6	36	7	6	108	3 mons	30

CHAPTER 2

EMP TESTING OVERVIEW

2.1 INTRODUCTION

Before considering detailed descriptions of EMP simulators, it is necessary to place the use of these simulators in perspective. The simulator is but one of several important tools used in an EMP assessment of a weapon system. Other tools include detailed pre-test analyses, assessment plans, measurement systems, data reduction and analysis, and post-test evaluation. Each of these are an important part of an assessment program, and if any one of them is slighted, the resulting assessment conclusions are placed in jeopardy.

The main goal in an assessment program is to test with an EM pulse that resembles the nuclear generated EMP. This criterion pulse is also used to obtain the input electric (and magnetic) fields for theoretical analyses of the weapon system. It is also the central design specification for the EMP simulator, and it is a critical input for the design of the experiment. At each step in an analysis or an experiment, it is important to relate the results to the nuclear generated EMP; as soon as this capability is lost, the value of all succeeding work is open to serious question.

The analysts use the criterion pulse as an input and theoretically calculate how the system will respond to the pulse. These calculations predict systems response and are used to determine critical points within a system, and are also used to design experiments.

Experiment design begins with the criterion pulse and theoretical predictions; the experiment is designed so that it can be related to the threat pulse and to the theoretical predictions. The analyst and the experimentalist work together in resolving differences in predictions and measurements. When these differences can be explained and are within acceptable limits, the experiment will probably yield meaningful data for later evaluation.

The final step in an assessment program is the post-test evaluation of all data. This post-test evaluation considers all analytical results, all experimental data, the measurement system used, the data reduction system, and previous assessments of similar systems. It carefully considers these data and determines the probability of system failure when exposed to the criterion EMP. Confidence limits are placed upon the probability estimates and depend upon the quality of the inputs to the evaluators.

2.2 EMP CHARACTERISTICS

It is desirable to simulate as nearly as possible the criterion pulse from an actual nuclear detonation. Conversely, it is also desirable to spend as little time and money as necessary to accomplish the task. To find the compromise point between these two conflicting goals, it must be determined what features of the criterion pulse are <u>necessary</u> in the simulation and what features are merely desirable.

A high-altitude nuclear burst produces a pulse of electromagnetic energy whose waveform, as viewed by a distant observer, is similar to that shown in Figure 2.1.

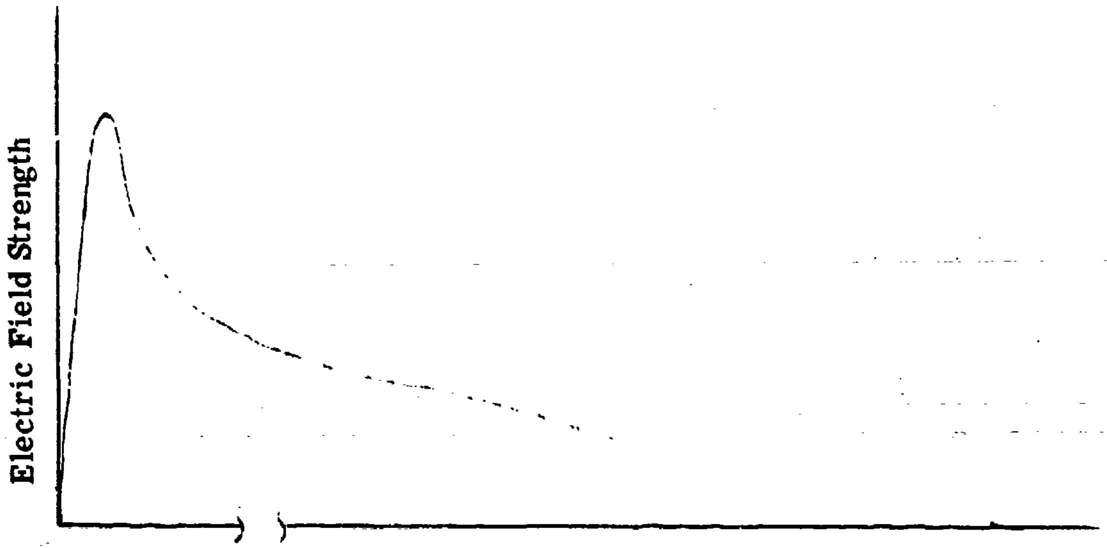


FIGURE 2.1. Representative Waveform for Nuclear EMP

The pulse is characterized by several parameters. These are:

a) risetime, which is of the order of nanoseconds and which determines the high-frequency components present in the pulse,

b) peak field strength, which is measured in kV/m,

c) decay time, which is of the order of hundreds of nanoseconds,

d) a parameter designated the very low frequency (VLF) content, which is related to the area under the curve of E versus t, or integral of E with respect to time, and

e) field uniformity; the high altitude EMP fields are essentially planar and very uniform over the dimensions of an airplane or missile.

If the Fourier transform of the pulse shown in Figure 2.1 is generated, a frequency domain plot similar to Figure 2.2 is obtained.

The low frequency content of the pulse is a quantity of great uncertainty because the late time behavior of the EMP is not (yet) well

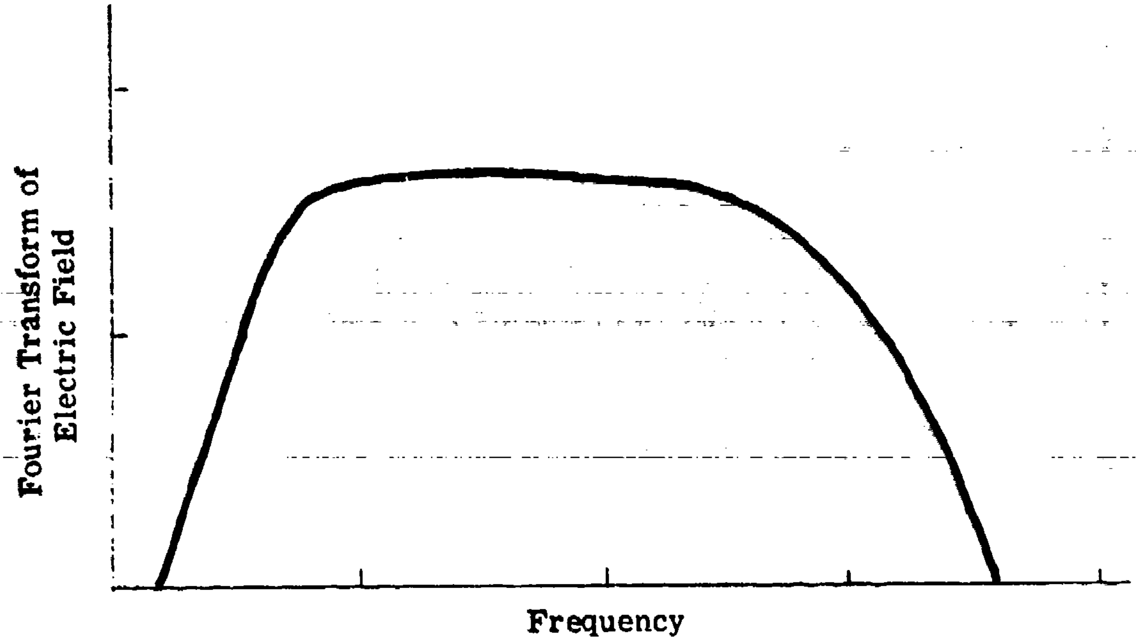


Figure 2.2. Representative Spectral Density for Nuclear EMP

understood. Because the nuclear burst producing the high-alt[illegible]de EMP is distant from the observer, the wavefront of the electromagnetic wave is planar to a high degree.

The precise details regarding nuclear EMP are classified and may be found in the "Electromagnetic Pulse Environment Handbook"*. The quality of the simulation discussed in the following summary should be measured with reference to this handbook or a similar document.

The criterion pulse is a worst case estimate of what the actual pulse from a real device will look like. It is usually an envelope that is a composite of actual measurements and extensive theoretical studies. The

*Schlegel, Radasky, and Messier, Electromagnetic Pulse Environment Handbook, January 1972, AFWL-EMP Phen. 1.1, AFWL, KAFB, NM (SRD).

EMP Handbook, Volume III, "Environments and Applications," DNA May 1972, (SRD).

criterion pulse has the following characteristics: it is a plane wave, i.e., it has a flat or plane wavefront, the electric and magnetic fields are perpendicular to each other and to the direction of propagation, and the ratio of E/H is 377 ohms.

The criterion pulse rises quickly in a few nanoseconds to its peak field strength, then decays exponentially. The amplitude spectrum of such a pulse is essentially flat in the low and mid frequencies and rolls off at high frequencies. The direction of the E vector in the criterion pulse is calle ts polarization. The polarization can be in any direction.

2.3 SIMULATION OF EMP

In choosing or designing a simulator for EMP testing, several parameters of the simulated pulse must be considered in regard to the experiment's threat relatibility . The most important of these parameters are discussed in the following paragraphs.

2.3.1 Field Polarization

In order to conduct a complete EMP test, fields that are polarized in all three principal directions must be produced. Of course, if fields can be produced in one horizontal polarization, a rotation of the simulator or test object will produce the other horizontal polarization. In general, a horizontally polarized field and a vertically polarized field are sufficient to simulate all possible polarizations.

2.3.2 Field Planarity

The wave will seem plane or flat to the test object if the radius of the curvature is two to three times the longest dimension of the test object. As stated above, one must be able to produce both a vertical and horizontal polarization. The E/H ratio should be as close to 377 ohms as possible, since there may be synergistic effects, that is, the combination of the two may produce effects which are greater than the sum of either field acting alone. The E/H ratio has not been found too difficult to achieve.

2.3.3 Field Strength

High field strength is costly and time-consuming to produce. It is possible to measure effects at low field strengths and then extrapolate to the criterion pulse field strengths. This is necessarily a linear technique and neglects any non-linear effects which might prove important. To interpret the extrapolated results, the damage thresholds for various components must be known.

2.3.4 Pulseshape-Frequency Content

It is not necessary to simulate exactly the criterion pulse shape or spectrum since by data handling techniques (transfer functions), one can find the response to the criterion pulse shape after measurement of the response to the simulated pulse. A transfer function is the ratio of the spectrum of the measured output to the spectrum of the simulator output. Multiplying the transfer function by the spectrum of the criterion pulse gives the spectrum of the criterion output. However, the data gathering and handling procedures put some restrictions on the spectrum of the simulated pulse. The phase spectrum is relatively unimportant so long as it is reasonably smooth. This is because almost all physical things respond best to a narrow range of frequencies where the absolute phase is not important and only phase differences can make second order effects. For the amplitude spectrum, however, one must consider the signal to noise ratio of the data gathering and handling procedures. If some part of the simulated spectrum is down by a factor of five or ten from the criterion spectrum, and if the signal to noise ratio is only five or ten to one, then all information from that depressed portion of the spectrum will be lost. Also, spikes or jagged amplitude spectra are difficult to digitize and further depress the signal to noise ratio. Therefore, a reasonably smooth amplitude spectrum that differs no more than a factor of five or ten from the criterion pulse over the frequencies of interest is needed. Translating these spectral requirements into the time domain results in a short rise time, a long crossover time, and a small undershoot.

2.3.5 Field Uniformity

Field uniformity is usually associated with the planarity or flatness of the wave since the field is generally uniform over a wavefront. The field uniformity is determined by the simulator characteristics and by the size of the test object. In general, it is desirable that field strengths vary by no more than 20% over the area covered by the test object.

Although the discussion above has dealt with only single pulse simulators, there are other types of simulation methods. One of these is CW, continuous wave, where the simulator is excited at a single frequency, the output measured for that frequency, then the simulator is excited at another frequency, etc., until the entire spectrum is obtained. Another technique is RPG, repetitive pulse generation, where the simulator is fired many times in succession. This is useful when combined with appropriate data recording techniques for improving signal to noise ratio. One difficulty with RPG may be that the repetitive output from the simulator interferes with necessary communications.

2.4 GENERAL SIMULATOR TYPES

Realistic simulation of nuclear EMP requires the use of high-voltage pulse generators (pulsers) and large antenna systems. Typically, pulsers producing high-voltages in the megavolt range are used to drive antennas with lengths of approximately a hundred meters. Different antenna geometries and modes of operation have been constructed for testing at various installations.

2.5 SIMULATORS FOR AIRPLANES

Airplanes present special problems in EMP simulation, some of which are fairly difficult to overcome. One problem is that simulators for airplanes must be near an airport; otherwise, it is impossible to get the airplane to the simulator. This establishes height restrictions, and it also establishes a criterion of non-interference with FAA electronic equipment.

Another problem with testing airplanes is the nature of airplane configurations. It is easy to simulate the circumstances under which parked airplanes see EMP, but it is not at all easy to properly simulate the in-flight configuration. Yet, the most important case is EMP on the airplane in flight. While an airplane is in flight, it is far removed from any reflectors or electrical grounds, but when parked, it is sitting on a huge reflector and ground plane (the earth).

Several types of simulators are potentially important for testing airplanes. Each of these is briefly described in the following paragraphs.

2.5.1 Vertical Dipole

The term "vertical" means that the antenna radiates a vertically polarized electric field. A vertically polarized EMP simulator most probably would consist of (1) an extended ground plane of the surface of the earth, (2) a high voltage pulser placed in the center of the ground plane, (3) a conic transition section between the pulser and the antenna, and (4) a cylindrical, impedance loaded antenna.

The major limitation of a vertical dipole is the vertical polarization of the pulse. The primary threat against airplanes in flight is an EM pulse with the majority of its energy polarized horizontally, and the normal airplane configuration will couple more efficiently to a horizontal pulse than to a vertical pulse. These two factors combine to cause the horizontal pulse components to be much more important to airplane testing than the vertical components. Nevertheless, a complete airplane test program should include both vertical and horizontal pulses, and the vertical dipole can be an important tool for part of the test program.

2.5.2 Horizontal Dipole

The first EMP simulator built was a horizontal dipole, the Sandia Long-Wire Facility. Horizontal dipoles are built by placing a pulser near the tops of telephone poles and using an antenna that is parallel to the ground and also supported by telephone poles. The antenna is horizontal and the simulator produces an electric field which is horizontal to the earth's surface.

One of the main draw-backs of a horizontal dipole is caused by the conducting ground surface. The E-field is launched parallel to the surface of the earth, but cannot be sustained horizontally near the earth's surface. High frequencies are reflected back and tend to cancel the incoming wave, while lower frequencies are absorbed. The resulting fields are complex and are quite dependent on position and height above the ground, but, in general, can be represented by a square wave whose width is only 20 nanoseconds. There is a longer lasting tail, but it is down by a factor of 5 to 10 from the peak value of the square wave.

The pulse shape tends to limit the quality of EMP simulation when testing an airplane with a horizontal dipole, but the limitation may not be as serious as one might initially suspect. The pulse obviously does not have as much low frequency content as the criterion pulse, but for many of the principle modes of energy penetration into airplanes this low frequency content may not be important. An airplane/simulator analysis must be performed before the value of testing an airplane with a horizontal dipole can be evaluated with confidence.

The fuselage of an airplane can sometimes be excited during inflight tests using a horizontal dipole if the proper airborne orientation is chosen.

2.5.3 Vertically Polarized Parallel Plate Simulator

At least three of these simulators are presently in use within DoD, the HEMPS at Fort Huachuca, as well as the ARES and ALECS at Kirtland Air Force Base. Since the energy is contained within the simulator, much higher field levels are possible in the test volume. The system is basically a transmission line, and can be used to develop a pulse that is quite similar to the criterion pulse.

The main limitation of a vertically polarized parallel plate simulator for testing airplanes is the polarization of the pulse, it is vertically polarized, while the main threats to airplanes (as previously mentioned) are the horizontal components of the criteria pulse. The only way this system can be used to couple horizontal pulses onto an airplane is to tilt the airplane in the simulator. Platforms for tilting airplanes are complicated and can be quite expensive to build.

2.5.4 Horizontally Polarized Parallel Plate Simulator

So far as is known, no such simulator presently exists, but one configuration of the Air Force TRESTLE facility, which is under development at Kirtland Air Force Base, is a horizontally polarized parallel plate simulator. This is considered to be an optimum simulator for testing airplanes; it couples in the important horizontal components of the pulse; it delivers a threat-level pulse that can easily be related to the criterion pulse, and it removes the airplane from the surface of the earth.

The TRESTLE facility is being built for testing such airplanes as the Advanced Airborne Command Post (747), the B-1, and the B-52, which makes the facility quite large and expensive. One could, however, use the TRESTLE design criteria and scale the size of the facility down to smaller dimensions.

CHAPTER 3

EXISTING SIMULATOR DESIGNS

3.1 GENERAL

In this chapter, several EMP simulators which already exist or which are presently on the drawing boards will be reviewed briefly. Later matrices summarizing and comparing the characteristics of the simulators will be presented. For the purposes of this study, four different test objects have been assumed to cover the range of test object dimensions which might be encountered in Navy EMP test programs. The assumed test objects are:

- A 3 meter long missile
- A 10 meter size missile
- An A-6 airplane
- A C-130 airplane

3.2 BOUNDED WAVE, TRANSMISSION LINE SIMULATOR

This class of simulator is probably the most common and most thoroughly analyzed of the various types of EMP simulators. In this type simulator an EM wave is launched into the volume between two conducting plates or grids of wires.

3.2.1 <u>ARES</u>

The Advanced Research EMP Simulation (ARES) Facility, sponsored by the Defense Nuclear Agency (DNA), was constructed by EG&G on KAFB under the auspices of the Air Force Weapons Laboratory during 1969. A high-altitude EMP environment is simulated for testing the vulnerability of defense missile systems. Minuteman, Sprint and Poseidon missiles have been tested in the facility.

3.2.1.1 System Description

Figure 3.1 is a pictorial view of the ARES Simulator.

Figure 3.1 Photograph of ARES Facility

Figure 3.2 is a simplified drawing of the ARES which shows some of the major dimensions. The simulator is composed of three major components: 1) the transmission line, 2) the high-voltage pulser, and 3) the terminator. Ancillary equipment includes the RF-shielded instrumentation room and the various EMP sensors, probes, telementry systems, and data recording devices.

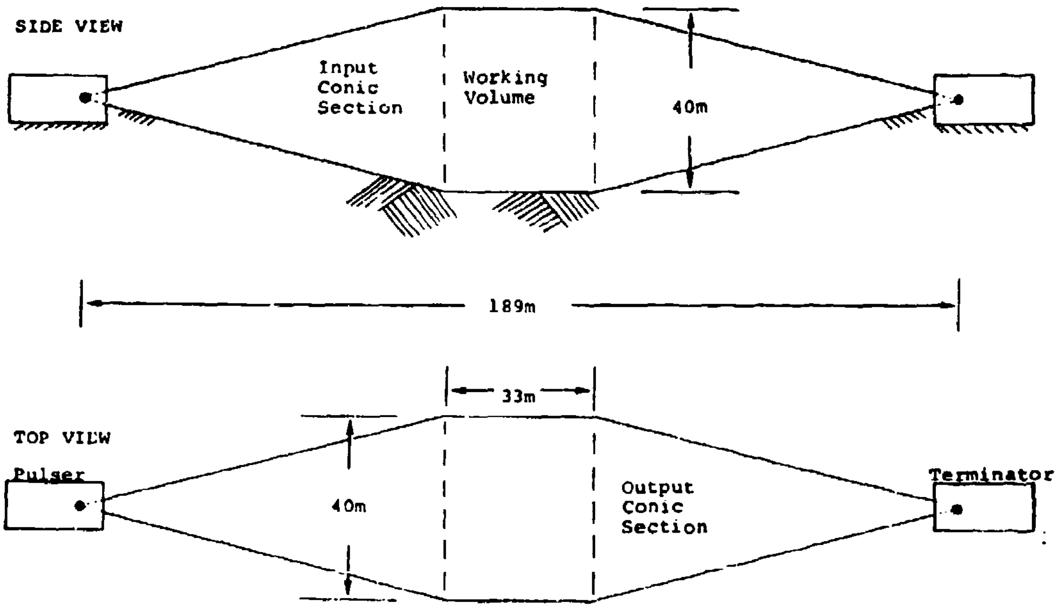


Figure 3.2 ARES Transmission-Line Geometry

The Transmission Line

The heart of the simulator is a 40 x 33 x 40 meter volume, bounded on top and bottom by the parallel plates of the transmission line, in which test objects are placed. This region, known as the "working volume", lies between two gradually-converging transmission-line segments (with the same cross-section shape as the working volume) known as the input and output conic sections (see Figure 3.2). The total length of the structure, as measured between the apexes of the conic sections, is 189 m. The plate separation in the working volume is 40 m.

The upper conductor, or top plate of the transmission line, consists of 75 equally spaced wires. The wires converge radially to the apexes in the conic sections, but they are parallel in the working volume. The bottom plate of the transmission line is formed of square-mesh material in the input conic section and the working volume.

A manway runs below the centerline of the input conic section. Access ports are spaced every 10 meters along the manway (Figure 3.3). These ports are 0.71 m in diameter and include circular steel plates that can be removed and be replaced by field sensors or by signal-cable feed-through plates. A total of 28 access ports are provided above manways constructed below the working volume.

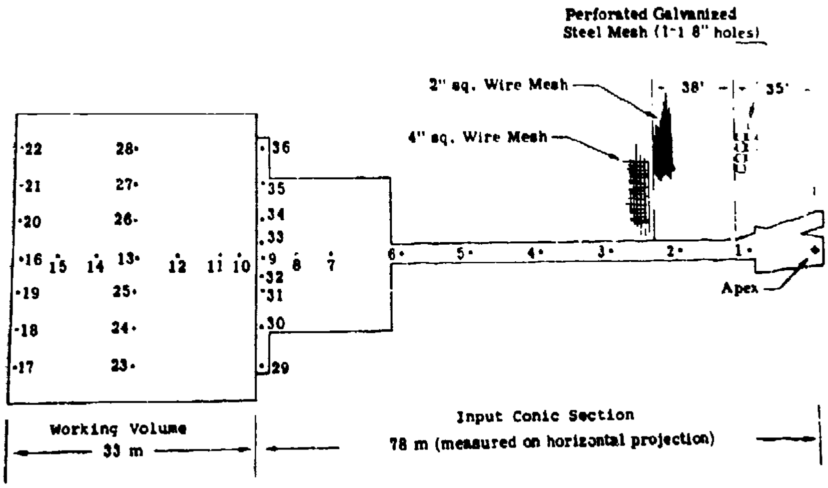


Figure 3.3 Access Port Layout (Plan View)

The Pulser

The high-voltage pulse generator for the ARES facility was constructed by the Ion Physics Corporation (IPC). The pulse generator (Figure 3.4) is basically a low-impedance coaxial gas-line which may be charged to peak amplitude by a Van de Graaff generator and discharged directly into the transmission line load. The generator charges a coaxial structure formed by a cylindrical pressure-vessel wall and a inner-cylindrical surface, which is coupled directly to the Van de Graaff generator. A mixture of sulfur hexafluoride (SF_6) and nitrogen, at 300 psig, is used as the dielectric medium within the pressure vessel. The effective radii of the inner and outer conductors of the energy store are 2.6 and 3.4 meters, respectively, thereby yielding a characteristic impedance of 15 ohms. The nominal length of the coaxial line is 8.5 meters; hence, the total capacitance is approximately 1.8×10^{-9} f and the total energy store (at 3.7 MV) is 16,280 J.

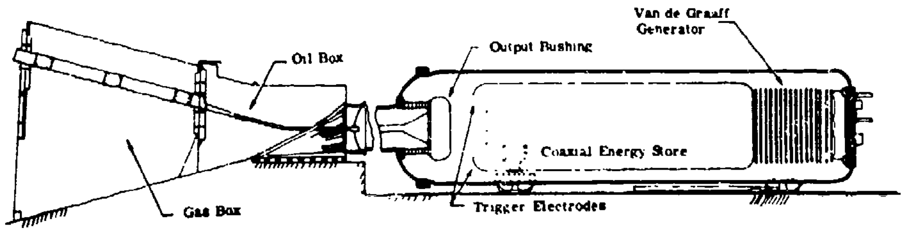


Figure 3.4 ARES High Voltage Pulser

An output switch consisting of six (6) electronically triggered channels initiates breakdown of the gap between the charged terminal assembly and the output bushing. There is also a standby switch that is triggered mechanically. The gap width is adjustable from 3.5 to 15 inches by means of an external gap control mechanism. Pulse amplitudes from 500 kV to 3.7 MV are attainable with risetimes of, at best, 6 ns, but more usually 8-9 ns.

The pulse then travels through an oil-filled coaxial line. An energy diverter is included just ahead of the line to vary the fall-time of the pulse from 100 to 500 ns. (The diverter is not normally used.) The decay of the pulse is approximately exponential. A second gap, known as the peaking gap may be used to further decrease the pulse risetimes. The spacing of the second gap is variable, but it is normally closed completely.

Transition Section

Next, the pulse enters a transition region known as the oil box where the transmission line is changed to a diverging-stripline geometry. The oil fill in this region is necessary to support the pulse amplitudes without voltage breakdowns between electrodes.

At the output of the oil box, the pulse passes through a vertical interface and into a gas-insulated region known as the gas box. This region is also required to prevent voltage breakdown and is designed for operation, with SF_6 or Freon gas, at one atmosphere pressure. The upper and lower conductors are solid plates in this region. A parallel-plate capacitor type of voltage monitor and a magnetic field sensor are located on the ground plane. The output of the gas box connects to the transmission line.

The impedance seen by the pulse as it leaves the coaxial energy store and propagates to the open transmission line is a complicated function of position. The impedance rises from 15 ohms at the coaxial store to about 125 ohms at the antenna. The varying impedance causes irregularities on the decaying portion of the output pulse.

Termination

The termination is so constructed as to result in transmission line parameters that vary exponentially. The fluid used in the termination is a solution of copper sulfate in water.

3.2.1.1 Support Facilities and Instrumentation

Support facilities include the Data Acquisition and Calibration Complex (DACC), the associated instrumentation, security and safety facilities, and general maintenance and support facilities.

The DACC complex, located under the conic section on the input side of the working volume, houses the shield room and work areas for the facility. The roof of this structure constitutes the floor of the conic section above. An 18-foot wide second level (mezzanine) extends along the back wall (opposite the working volume). All mechanical equipment (air conditioning, heating, etc.) is housed on this mezzanine.

A buildup room and an instrument calibration room are provided in the DACC. Data recording equipment is housed in a doubly shielded room which provides an attenuation of 120 dB from 1 MHz to 10 GHz.

The pulser charge level is continuously monitored by a digital voltmeter. Mechanical counters record the number of pulser discharges. Diagnostic instrumentation is installed at the facility for monitoring the output of the pulse generator. Instrumentation racks in the shield room house 28 oscilloscope/camera units for displaying and recording the microwave and hardwire output waveforms. Data may be from working volume sensors, environmental detectors, or the microwave receivers.

The microwave telemetry system consists of two transmitter/receivers (connected by dielectric waveguide), four channels and six channels respectively, thus providing a three-way packaging capability, namely four, six and ten channels. Signal sensitivity is 200 microvolts into 50 ohms at the input. The system has a 40 dB dynamic range over a bandwidth from 10 kHz to 110 MHz. The system can transmit bipolar pulses and/or continuous sine wave signals as required by an EMP test. The transmitter on/off and operate/calibrate functions are controlled pneumatically to preserve the RF tight integrity of the transmitter box.

3.2.1.2 Electromagnetic Characteristics

The electromagnetic characteristics of a bounded-wave vertically polarized simulator such as ARES are well understood. The geometry of the transmission line determines its impedance. For the ARES geometry, the height to width ratio is equal to 1.0; however, the ground is effectively an infinitely wide conducting plane so the equivalent height to width ratio for a two-plate stripline in free space is 2.0. This implies an impedance of approximately 127 ohms.

The electric field in the ARES facility is vertically-polarized. The low-frequency field distribution for the ARES geometry is shown in Figure 3.5. The crosshair symbols overlaid on the plot denote points at which B-field measurements were made during the evaluation of the facility. The plot is valid for any position along the axis of the simulator (i.e., for any value of x) since the geometry is such that the impedance remains constant. The propagating wave is almost exclusively the TEM mode; hence, the ratio of electric field E, to magnetic field B, is fixed at the speed of light, $c = 3 \times 10^8$ m/s, equivalently, E/H = 377 ohms. The plot in Figure 3.5 gives the local E-field direction (lines approximately perpendicular to plates) and local B-field direction lines parallel to plates). The line density near a point is proportional to the field intensity at the point.

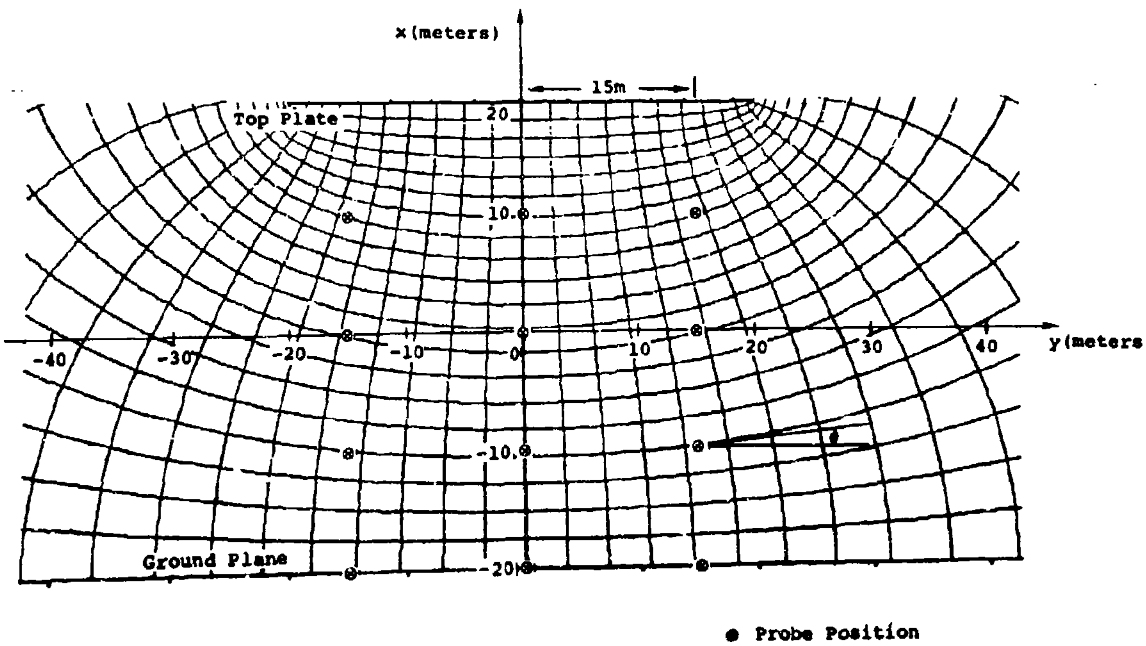


Figure 3.5
Field Distribution Plot for Transmission Line with Infinite-Width Lower Plate and Top Plate with Width Equal to Plate Separation

For any given charge voltage of the pulser, the risetime and peak amplitude of the output pulse vary with the pulser's main gap spacing.

Pulse risetimes are minimized by reducing the gap spacing (and therefore, the gap inductance); peak amplitudes are maximized also by reducing the gap spacing.

In order to prevent damage to the generator, charging voltages are limited to about 3.7 MV. At this voltage, one can expect peak working volume field amplitudes of 92.5 kV/m and a large proportion of risetimes on the order of 8 ns.

The amplitude of the signal reflected from the terminator is somewhat dependent upon the measurement point. Measurements at port 7 showed a reflected B-field arriving 810 ns after the incident pulse with an amplitude of 18% of the incident pulse and opposite in polarity. The reflected E-field, arriving at port 8 760 ns after the incident pulse and with the same polarity, had an amplitude equal to 10% of the incident pulse. Smaller reflected signals from the transmission lines input arrived at port 8 after about 1470 ns. The field amplitudes resulting from the reflections at both ends of the array decay to zero in roughly 3.4 μs.

An example of the B-field pulse measured at the leading edge of the working volume is shown in Figure 3.6. The pulse voltage of +2.5 MV yielded a peak E-field of about 62 kV/m, as expected. The frequency transform for this pulse is shown in Figure 3.7. Note the significant notch at a frequency of ~ 17 MHz which corresponds to the resonance frequency of the gas chargeline pulser.

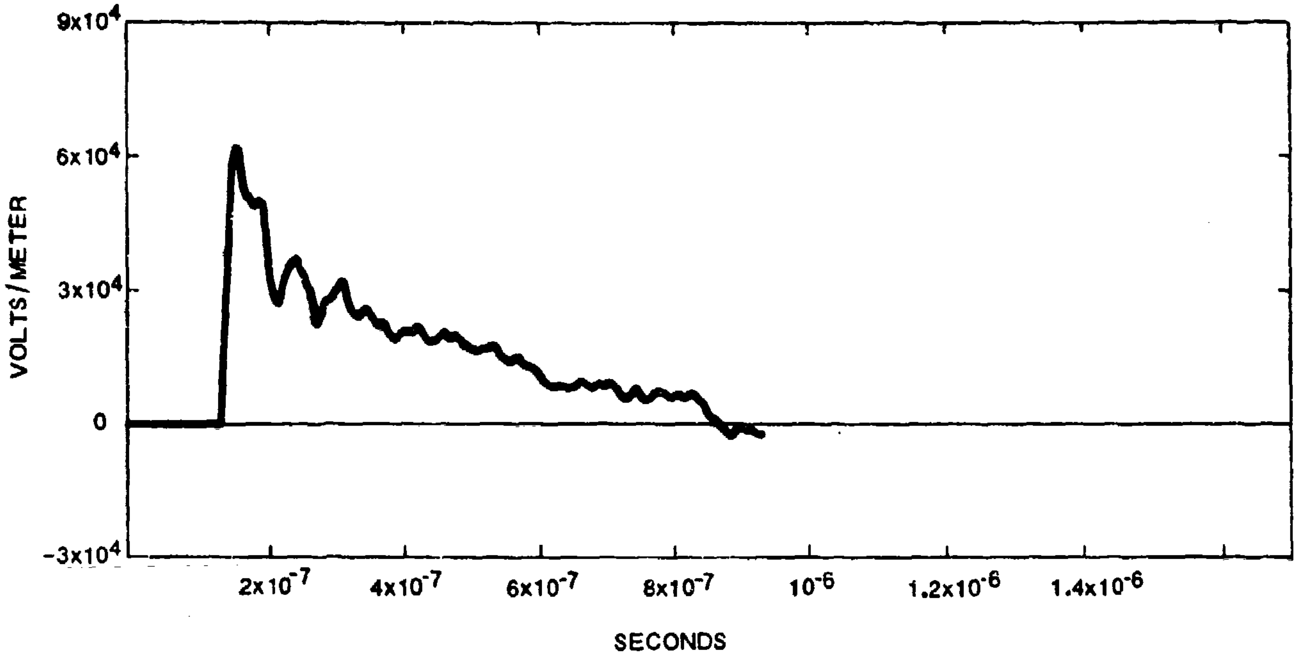


Figure 3.6 ARES Time Domain Waveform

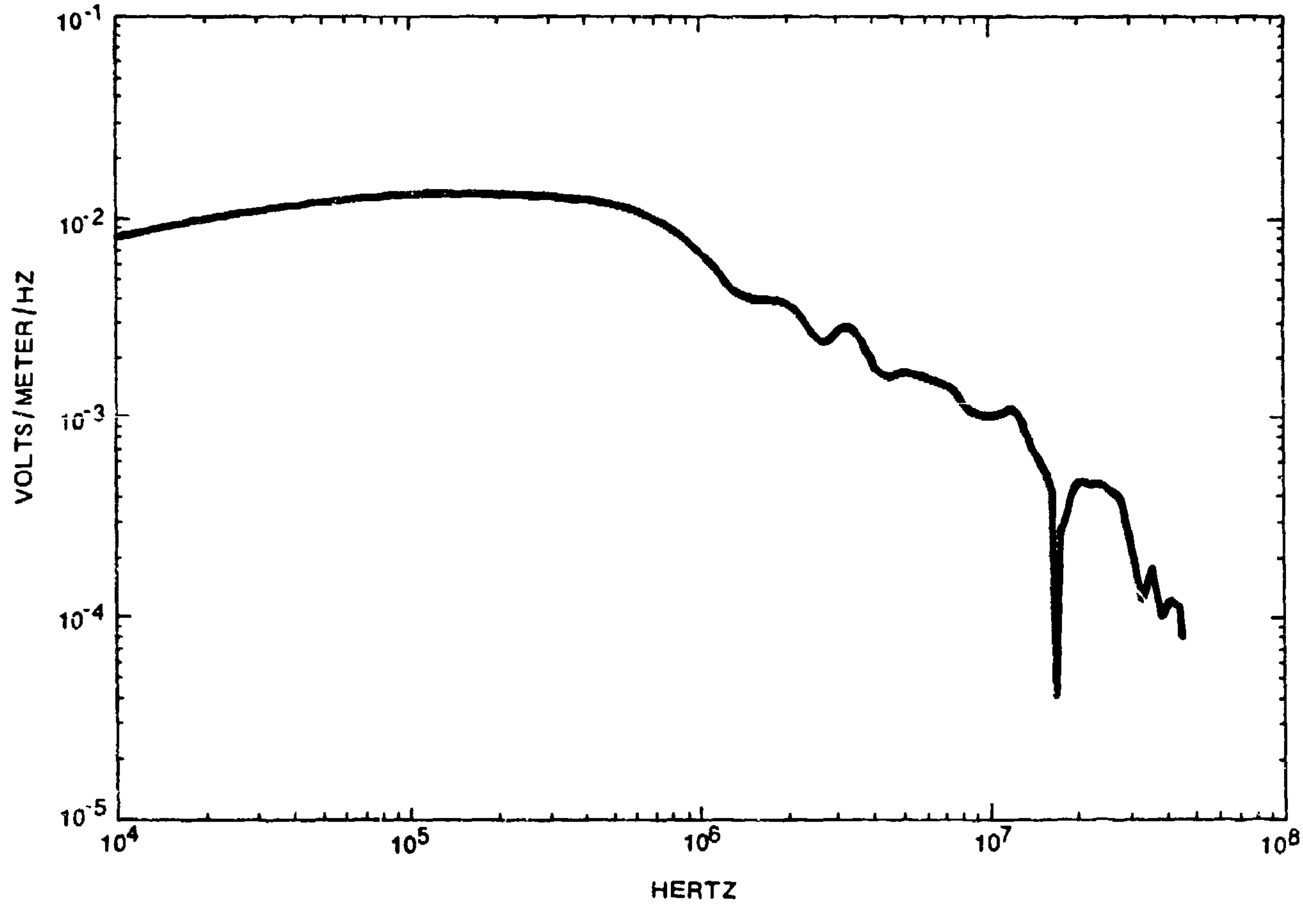


Figure 3.7 Frequency Transform of ARES Pulse

3.2.1.3 Administrative Data

The ARES facility is operated by the Defense Nuclear Agency (DNA). The DNA Project Officer is Mr. John Farber who can be reached by telephone at 703-325-7067.

In March 1974, the Air Force Weapons Laboratory (AFWL) is scheduled to begin a six (6) month test of the FB-111 airplane. Later in 1974, modifications of the ARES will be made for the simulation of a dispersed pulse as would be incident on a satellite. Satellite testing is being considered for 1975-76.

Rental costs for the ARES facility range from 2 to 2.5 thousand dollars per day of operation. The fee is based on a single shift, 5 day per week facility operation with the support of DNA's ARES technical and data acquisition staff. More information regarding facility schedules or rental costs can be obtained from the DNA Project Officer.

3.2.1.4 Reference Information

More detailed information concerning the design and operation of the ARES facility can be obtained from the following sources:

- "Electromagnetic Pulse System - Van de Graaff Generator Design", AFWL-TR-69-15, September 1969.
- "ARES Low-Voltage Evaluation", AFWL-TR-71-10, April 1972.
- "ARES High-Voltage Evaluation", AFWL-TR-71-9, April 1972.

- ARES Facility Brochure (available from DNA)
- "EMP Simulation Facilities for Aeronautical Systems EMP Program", June 1972 (available from AFWL).
- "Electromagnetic Pulse Handbook For Missiles and Aircraft in Flight", SC-M-710346, September 1971, Sandia Laboratories.

3.2.2 ALECS

The ALECS facility provides a controlled high-voltage generation system for simulation of EMP environments. This facility was constructed on KAFB for the AFWL. The ALECS facility was the forerunner of the ARES facility. In most technical aspects and general layout it is identical to the ARES facility. The Polaris, Poseidon, and Minuteman missiles are among the strategic systems which have been tested in the facility.

3.2.2.1 System Description

A photograph of the facility with a Minuteman Missile undergoing testing is shown in Figure 3.8. An annotated sketch showing the basic facility components is shown in Figure 3.9.

The basic simulator is composed of three major components; 1) the transmission line, 2) the high-voltage pulser, and 3) the termination. Ancillary equipment includes the RF-shielded instrumentation room and the various ancillary systems and devices.

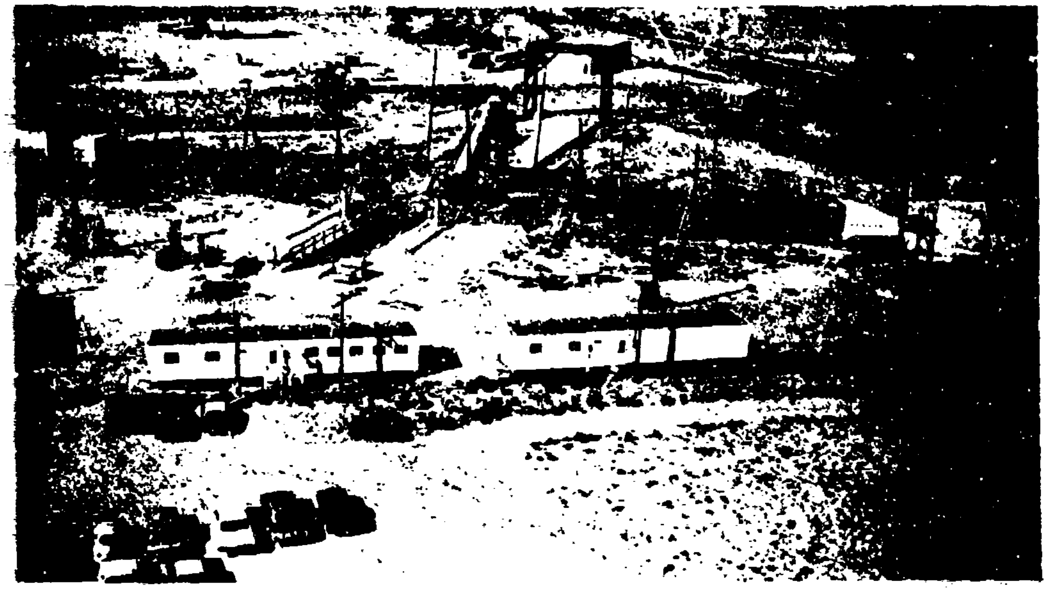


Figure 3.8 Photograph of ALECS Facility

The Transmission Line

The heart of the simulator is a 26.9 x 15.24 x 12.75 meter high working volume, bounded on the top and bottom by parallel plates of the transmission line. Figure 3.9 shows the working volume and the tapered

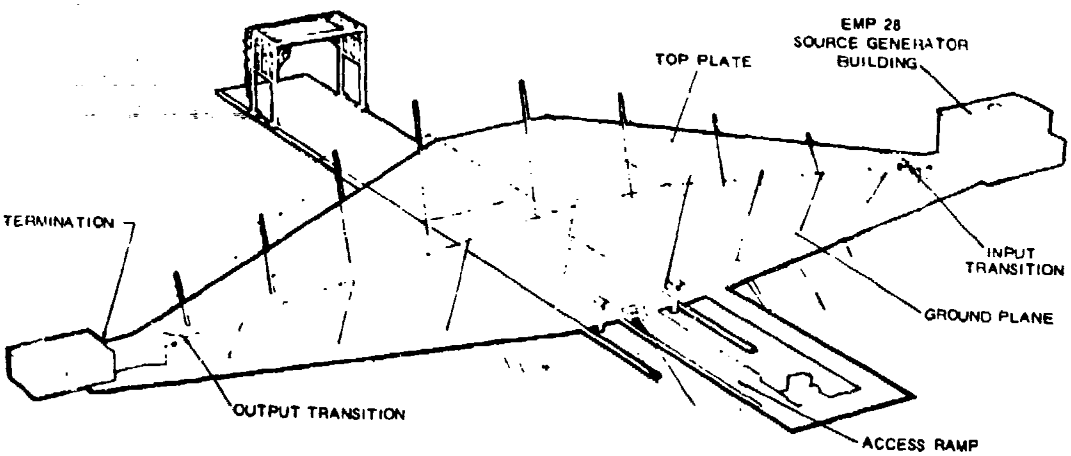


Figure 3.9 ALECS Structure

transition sections. The upper conductor, or top plate of the transmission line, consists of equally spaced wires running from the launch structure to the termination structure. The support structure, which supports the top plate wires, lifts them to 12.75 meters above the ground plane. The top plate was recently modified by covering the wires with 2-inch hexagonal wire netting to enhance high-frequency performance.

A perforated aluminum sheet ground plane covers the entire ground level beneath the wire structure from the pulser apex to the termination apex. The transmission line impedance is approximately 95 ohms.

Pulser

The high-voltage electromagnetic pulse is produced by discharging a graded capacitor stack into a short 41 ohm coaxial transmission line (the peaking capacitor concept) and by discharging the series combination into a transition structure that mates with the ground plane and parallel wire top plate of the array. The 41 ohm coaxial line provides for the initial nanoseconds risetimes of the wave while the graded capacitor stack provides the large amount of energy in the remaining portion of the wave. The pulse launching system in energized by a 2.2 MV Van de Graaff generator prior to discharge. This system can generate an electromagnetic pulse having a risetime from 1 to 10 ns, depending on pulser charge level. The minimum effective charge on the generator is 100 kV. When the generator is charged to 2.23 MV, the stored energy is 1.8 kJ.

The input transition allows the pulse to be launched into the transmission line without arcing or corona. This transition has a conical simulatingoil-filled section, a matching conical 1 atmosphere sulphur hexafluoride filled section, a ground plane top plate electrode, a connecting segment, and a capacitor E-field monitoring sensor.

The facility includes a 50-kV repetitive pulser which produces lower field strengths with repetition rates of up to 60 pulses per second. The RPG-2 system can also be operated in single shot mode.

The facility is undergoing modification for continuous wave(CW) testing. A 400-watt, 250-MHz CW system has been installed.

Termination

As a part of the CW modifications, a new terminator has been designed and installed. It consists of five parallel strings of resistors. Each string consists of seven resistors. A combination of wire-wound and carborundum resistors is used to provide optimum resistance and inductance values.

Instrumentation

The instrumentation system is housed beneath the working volume in an area approximately 43 feet x 60 feet. A portion of this space is contained within a screen room which provides isolation from external EM fields. The instrumentation rooms are connected to a 120 foot tunnel extending under the launching transition section to permit installation of enivronment monitoring sensors in the launch transition area.

The instrumentation equipment provided at the ALECS facility consists of a 10-channel microwave data acquisition system, a single channel microwave data acquisition system, a hardwire data system, , trace recording system and attendant checkout and monitoring equipment. Most of these systems are housed in the double-walled screen room which affords 120 dB attenuation of the E and H waves.

Gantry Crane

A 42-foot high, 15-ton, gantry crane is provided for transportation and positioning of the test items. The maximum height of the base of the hook above the ground plane is 37 feet. The distance between the gantry legs is 34 feet.

3.2.2.2 Electromagnetic Characteristics

Low-voltage field measurements have shown the simulator performance to be as expected with a field distribution plot similar to that shown earlier for ARES. The measurements showed the simulator to be capable of propagating a vertically-polarized pulse with a risetime of less than 0.5 nanoseconds. Reflections and diffractions from the top plate were found to agree in terms of arrival times and amplitudes with theoretical predictions. Measurements of the E-field and B-field on the ground plane at the leading edge of the working volume confirmed the expected E/B ratio equal to the speed of light. The predicted r^{-1} fall-off in initial pulse amplitude (r equal to distance from input apex) was also confirmed.

The fields present in the facility for an actual test must be scaled to the actual input pulse characteristics. The magnitude of the electric field in this facility is approximately the capacitor charge voltage divided by the spacing (d) between the plates. The actual electric field in the working volume is only about 70 - 80% of the calculated value, possibly due to the back radiation, the expansion of the wave, and reflection at the generator. A typical $E_v(t)$ oscillograph is shown in Figure 3.10. It should be noted that $E/H = 120\pi$ $(E/B = c)$ until reflection or diffraction occurs. Measured H-fields in this facility are nearly identical to the E-field in shape. A Fourier transform of B (t) in the working volume is presented in Figure 3.11.

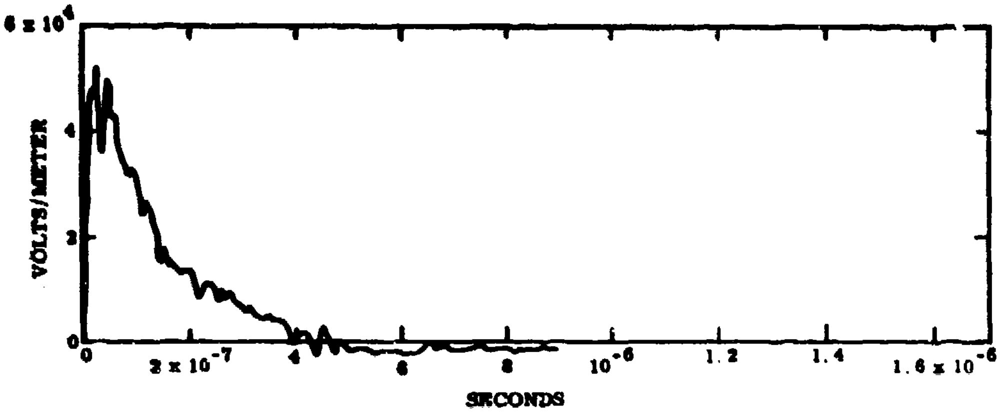


Figure 3.10 E(t) In The Working Volume At The ALECS Facility

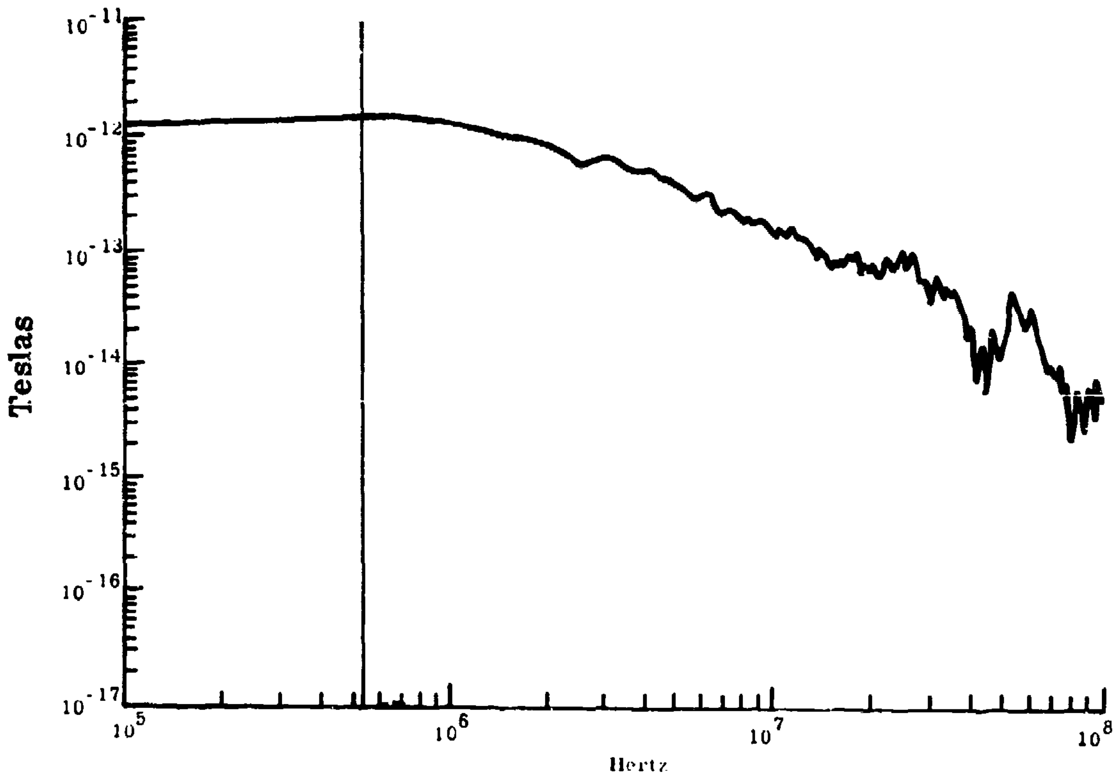


Figure 3.11 Fourier Transform of B(t) in ALECS Working Volume

3.2.2.3 Administrative Data

The ALECS facility is operated by the Air Force Weapons Laboratory (AFWL). The AFWL Project Officer is:

Major Bruce Sanderson
AFWL/ELT
Kirtland AFB, New Mexico 87114
Telephone: 505-247-1711, extension 2896

A scale model of a B-1 airplane will be tested in the facility during 1974. Rental costs for the facility run approximately $15,000 per month based on a standard 5-day-week, single-shift schedule. This includes a basic simulator operation and maintenance crew. The above estimate is based on past test programs. The user would pay all costs actually incurred during the test. Further details concerning simulator scheduling should be obtained by contacting AFWL/ELT.

3.2.2.4 Reference Information

More detailing information concerning the design and operation of the ALECS facility can be obtained from the following sources:

- "ALECS EMP Simulation Facility" (brochure available from AFWL/ELT).
- "ALECS I Special Report on Field Measurements", EG&G Report AL-186, December 1967.

- "EMP Simulation Facilities for Aeronautical Systems EMP Program", June 1972 (available from AFWL).
- "Electromagnetic Pulse Handbook for Missiles and Aircraft in Flight", SC-M-710346, September 1971, Sandia Laboratories.

3.2.3 TRESTLE Facility

The TRESTLE concept was developed to eliminate the serious limitations of ground-based testing of airplanes. Interaction of the conducting ground with the EM wave causes unwanted effects which make simulation of in-flight conditions difficult. Basically, a large dielectric support platform will be used to remove the airplane from the vicinity of the earth. The structure will resemble a very large railroad trestle (hence the name). The facility is now being designed and constructed by McDonnell-Douglas for the AFWL.

3.2.3.1 System Description

The TRESTLE facility will be located on Kirtland AFB near the ARES and HPD facilities (see Figure 3.12). An artist's conception of the TRESTLE facility during airplane testing is shown in Figure 3.13.

Antenna

Two antenna systems will be built: one for vertical polarization of the E-field and the other for horizontal polarization of the E-field (see Figure 3.13). With the dual simulator concept, two airplanes can be tested simultaneously.

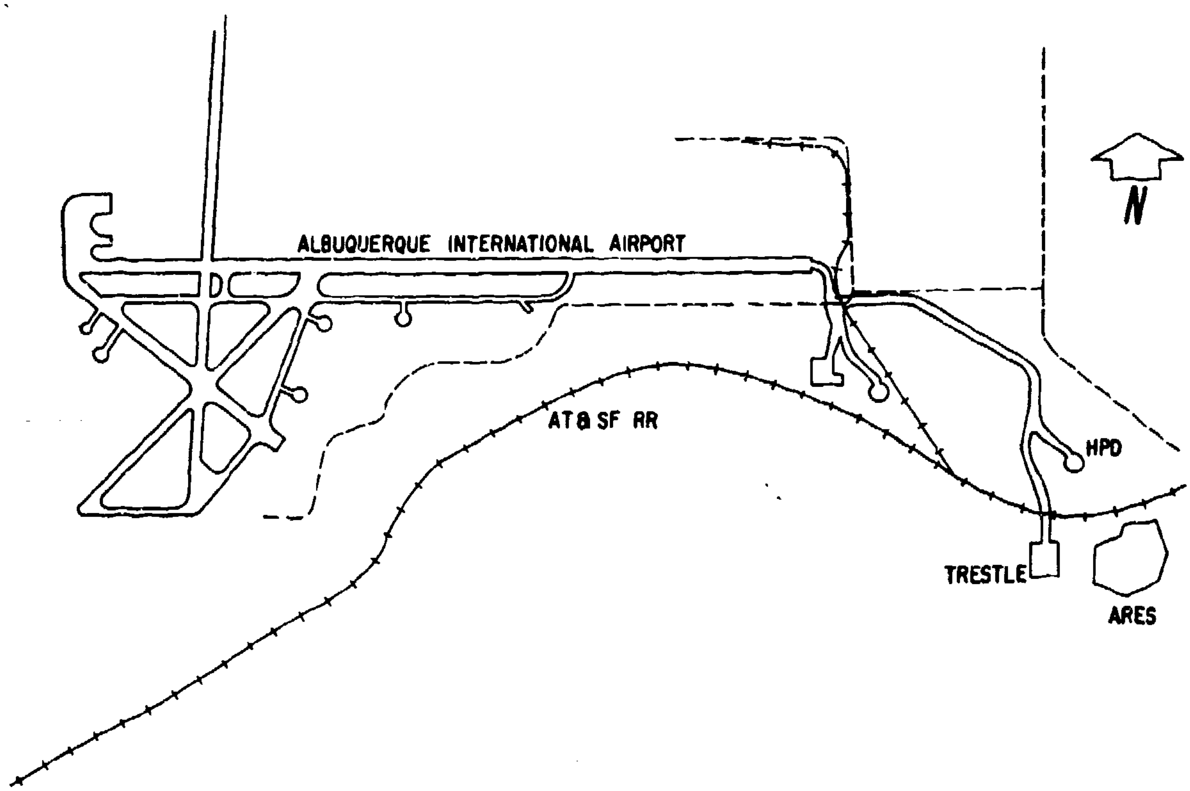


Figure 3.12 TRESTLE Facility Location

Basically, the antenna will consist of a diverging transmission line from the pulse generator(s) to the working volume. Here the transmission line will be of the parallel-plate type to provide an essentially TEM wave within the working volume. From the working volume, the transmission line converges to the termination.

Figures 3.14 and 3.15 illustrate the dimensions of the two simulators. The working volumes of both simulators are 75.7 meters in diameter.

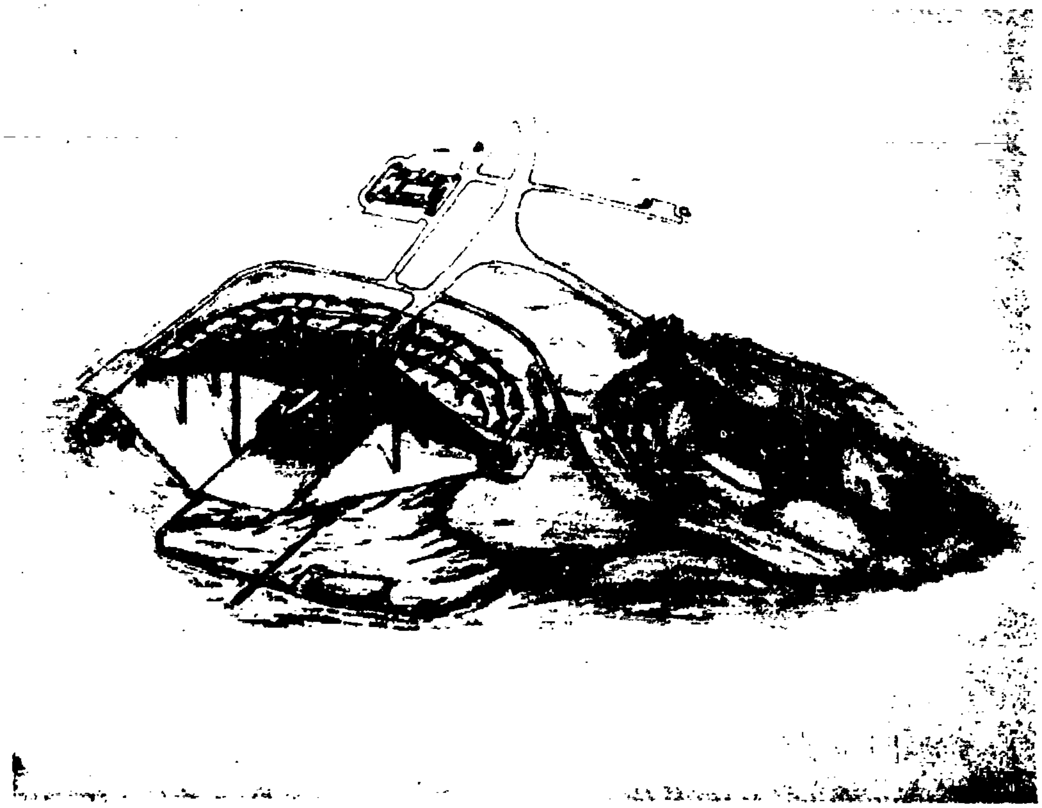


Figure 3.13 Artist's Conception of TRESTLE Facility

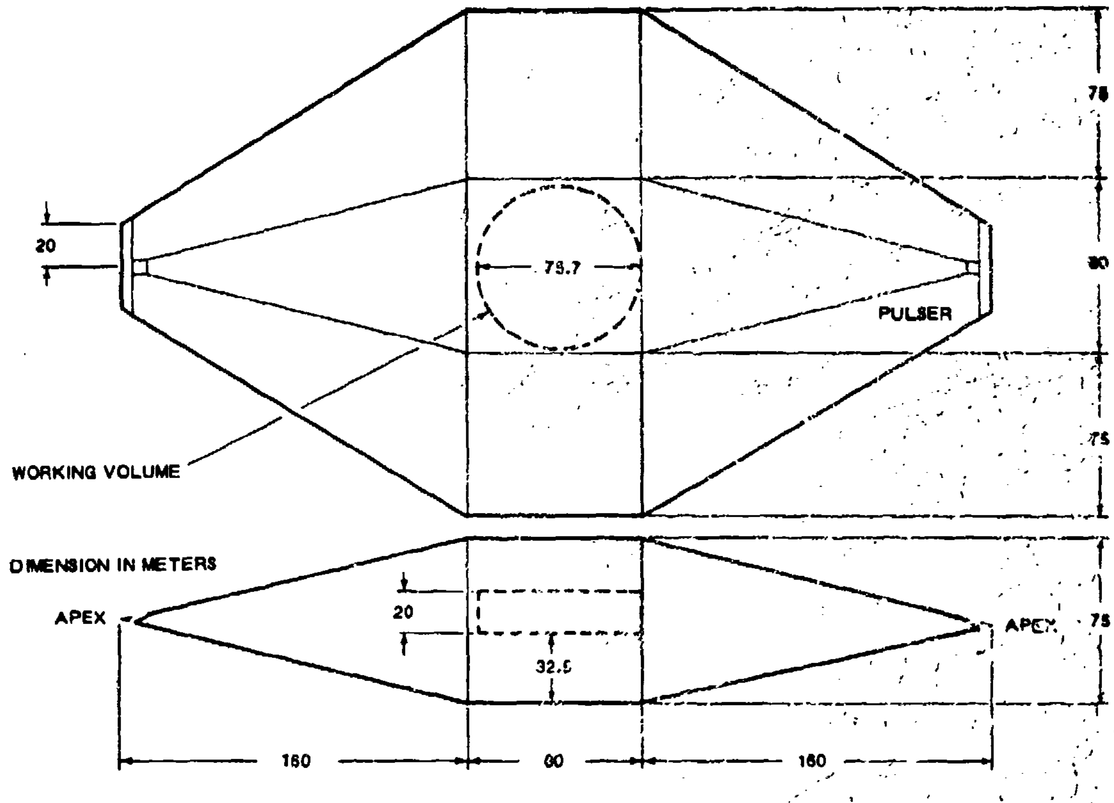


Figure 3.14 Vertical TRESTLE Dimensions

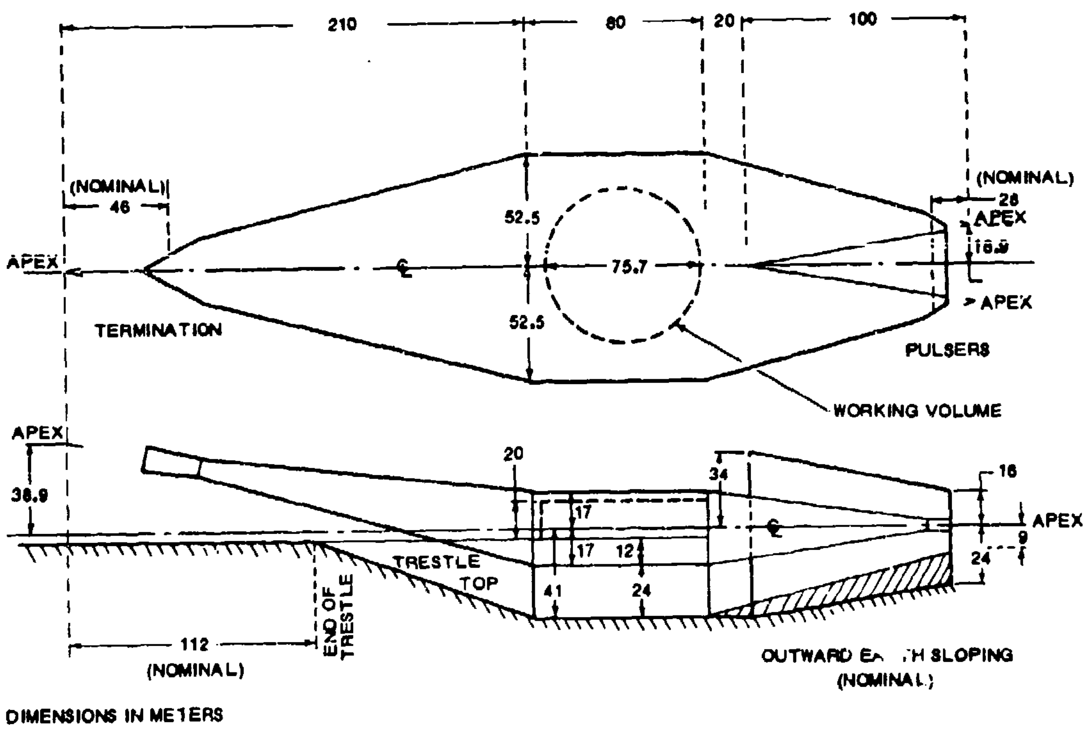


Figure 3.15 Horizontal TRESTLE Dimensions

Pulser

The pulse generator for TRESTLE will consist of a number of small pulse units. One of these units, utilizing a Marx Generator and a peaking capacitor, is shown in Figure 3.16. For the horizontally polarized simulator, four such pulsers are used. On either side of the metal wedge at the input end of the horizontal simulator (Figure 3.13), two pulsers supply a potential between the wedge and the parallel wires of

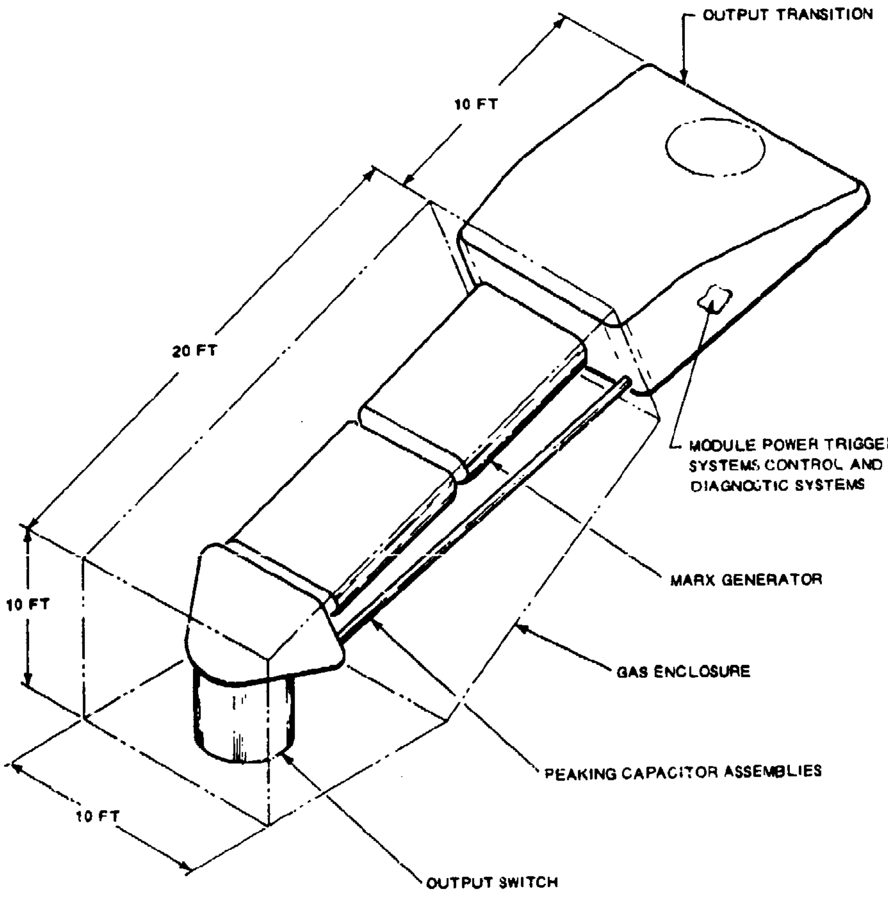


Figure 3.16 TRESTLE Pulse Module

the antenna. The field from the two sides of the input section add together in the working volume to give the total voltage between the parallel wire plates. The vertically polarized field simulator utilizes only one pulser.

Terminator

A solid resistor terminator design similar to that installed in ALECS will be used in the TRESTLE facility. The elevated terminator for the horizontal simulator has been designed to allow rapid transit of test objects along the taxiway.

3.2.3.2 Electromagnetic Characteristics

Figure 3.17 shows the time domain output specifications for one pulser. The general pulse shape is a double exponential with a 500 ns decay time and a 10 ns risetime. The frequency domain plot for this pulse is shown in Figure 3.18. The general waveform is given by:

$$\tilde{V}(f) = \frac{V_m}{2\pi jf + \beta}$$

where: $\beta^{-1} = 500$ nsec, and

V_m is the pulser charge voltage.

Since TRESTLE is not yet operational, the exact waveshape which will be present in the working volume is not yet known. The design goals for working volume fields are listed in Table 3-1; the simulator's actual performance should be similar.

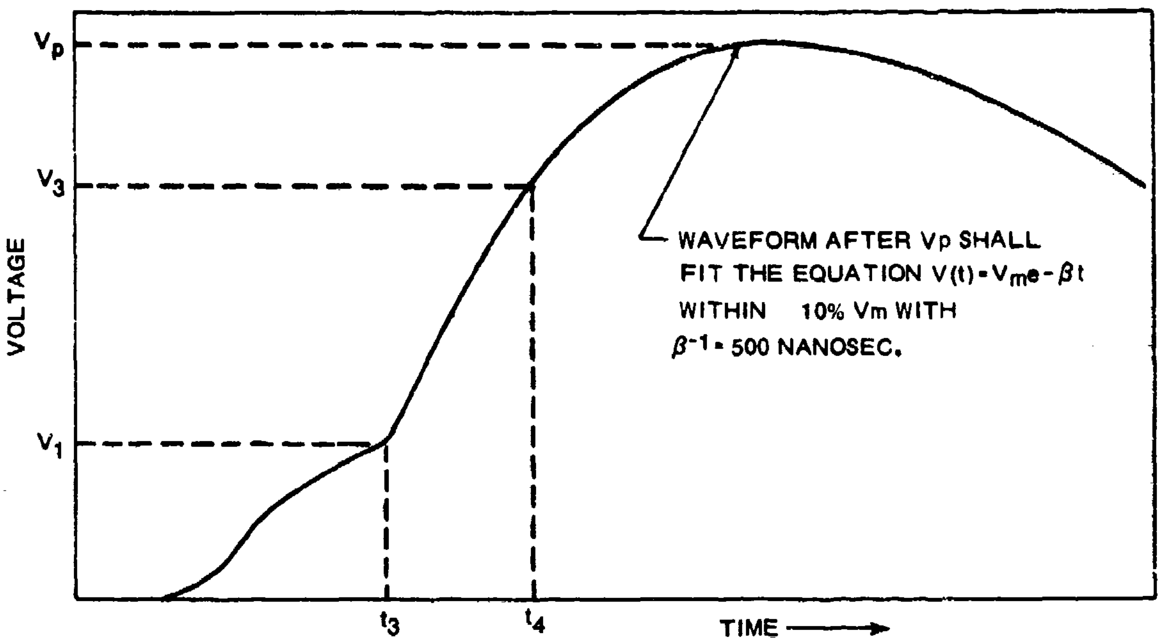


Figure 3.17 General Shape of Time Domain Voltage Waveform Produced by Pulse in Test Fixture

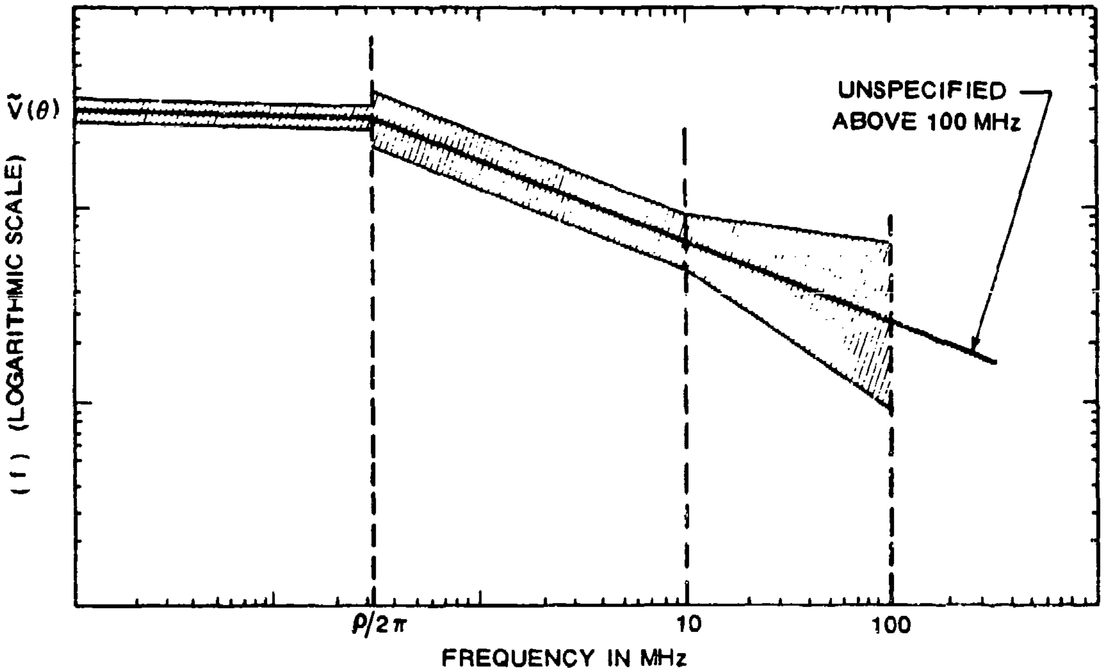


Figure 3.18 General Shape of Frequency Domain Voltage Waveform Produced by Pulser in Test Fixture

TABLE 3-1

Approximate TRESTLE Working Volume Field Characteristics

1. Ideal Wave Shape	Double exponential	$E(t) = E_o (e^{-\alpha t} - e^{-\beta t})$
2. Maximum Peak Amplitude (E_p)	Horizontal Simulator	100 kV/m
	Vertical Simulator	50 kV/m
3. Wave Risetime(T_r)		10-90% $\leq$20 nsec
4. Decay Time Constant(T_d)		$\approx$500 nsec
5. Electric Field Polarization	Horizontal and Vertical in Separate Systems	
6. Waveform Distortion	See Figure 3.17	
7. Frequency Distribution	See Figure 3.18	
8. Prepulse	The amplitude of the prepulse shall not exceed 20% of the peak amplitude (E_p). The duration of the prepulse shall not exceed 100 nsec.	

9.	Reflections	The amplitude of termination reflections shall not exceed 10% of the peak amplitude E_p at any time.
10.	Field Non-Uniformity	The field non-uniformity shall not exceed 20%
11.	Wave Front Distortion	The wave front distortion shall not exceed 10 nsec.
12.	Waveshape Deviation	The waveshape deviation shall not exceed $\pm 10\%$

3.2.3.3 Administrative Data

TRESTLE is being built and will be operated by the Air Force Weapons Laboratory (AFWL). The AFWL Project Officer is:

Major Walter L. Futch
AFWL/ELS
Kirtland Air Force Base, New Mexico 87114
Telephone: 505-247-1711, extension 3895

The horizontally polarized field simulator will be operational in January of 1976. At this time, a four month test of the Advanced Airborne Command Post is scheduled to being. The vertically polarized field simulator is scheduled for completion in March 1976. Later tests in the facility are planned for the Airborne Warning and Control System (AWACS) and for the B-1 bomber.

Rental costs for use of the TRESTLE facility are estimated to be about $125,000 per month. The fee includes use of both simulators, instrumentation and the two screen rooms, one for each simulator. Each screen room is divided in half, one part for the user, the other for TRESTLE operations. More detailed information concerning facility scheduling can be obtained by contacting AFWL/ELS.

3.2.3.4 Reference Information

More detailed information concerning the design of the TRESTLE Facility can be obtained from the following sources:

- "TRESTLE Design Study", Volumes I-III, EG&G Report Al-661, November 1971.
- "EMP Simulation Facilities for Aeronautical Systems EMP Program", June 1972, (available from AFWL).

3.2.4 HEMPS

The Huachuca EMP Simulator (HEMPS) is a bounded-wave two-plate EMP simulator located on the West Range of Fort Huachuca, Arizona. It consists of a pulser, a two plate transmission line and a termination. The HEMPS facility presently uses the "T-8" pulser and a stacked Cable Voltage Source. The output termination also employs a stacked cable voltage source configuration.

The facility includes an underground screen room and extensive instrumentation for timing, firing, and monitoring the incident field.

3.2.4.1 System Description

Figure 3.19 shows the layout and important dimensions of the HEMPS Simulator. The underground screen room is near the 15.2 meters apex of the simulator.

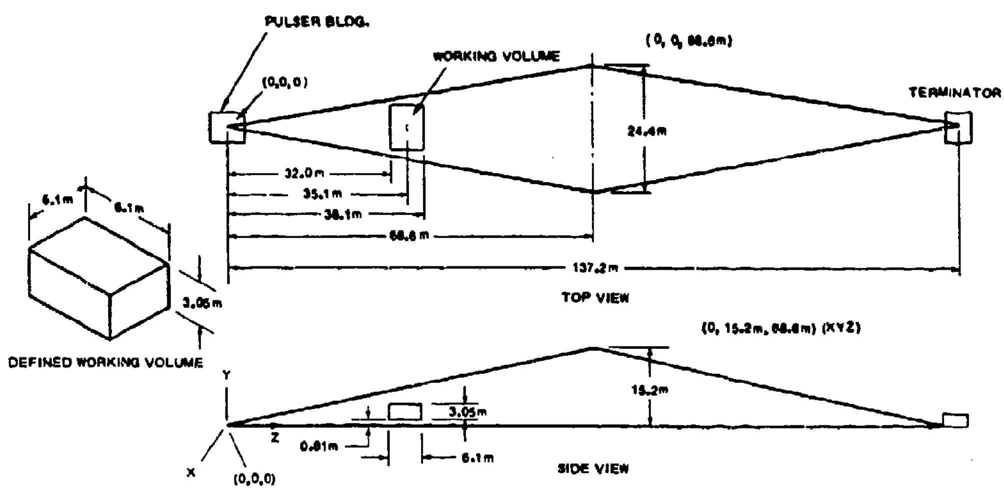


Figure 3.19 HEMPS Dimensions

Simulator

The HEMPS Simulator is a bounded wave, two plate transmission line type simulator. The ground plane forms one plate of the transmission line and a series of wires leading from the pulser to the terminator forms the top plate. The top plate tapers symmetrically from a 15.2 meter high apex halfway between the pulser and the terminator. The working volume is normally considered to be located in the input transistions as shown in Figure 3.19 but the entire length of the simulator can be used from the defined working volume to the apex. Maximum field strengths are obtained close to the pulser and 100 kV per meter field strengths have been obtained at the 8 meter plate separation point.

A series of 22 portholes are located on the ground plane along the array centerline and are connected to the underground screen room by a 12 inch conduit. Signal, communication, and control lines are enclosed in this conduit. Access to the underground screen room is gained by means of a stairwell located at one side of the simulator.

Pulser

The HEMPS facility is presently equipped with the T-8 pulser. The significant feature of this pulser is that it can drive 48 cables in parallel at relatively low voltage (100 kV). The T-8 pulser is essentially the same as the T-7 pulser except that it consists of only one module instead of six. A description of this module is given in the TEFS array discussion which follows.

The 100 kV T-8 pulse output voltage is multiplied by the stacked cable voltage source. The HEMPS array uses eight groups of six cables to multiply the T-8 pulser output by a factor of eight. Thus, the maximum pulse into the HEMPS simulator is 800 kilovolts, resulting in 100 kV/m at the 8 meter plate separation.

Termination

The HEMPS simulator uses a stacked cable voltage source termination. The output transition has 8 groups of six cables that absorb the simulator's pulse in series and delivers it in parallel to a bank of terminating resistors. The termination resistors thus only need to withstand 100 kV.

Instrumentation

Extensive instrumentation is available at the HEMPS facility. The underground screen room has five racks containing oscilloscopes, signal distributions panels, pulse generators and remote timing units. The above ground screen room has additional oscilloscopes, timing and firing equipment, communications equipment and the pulse controls.

3.2.4.2 Electromagnetic Characteristics

The electric field in the HEMPS is vertically polarized. As stated earlier, field strengths of up to 100 kV/m can be obtained for small (~ 5 meter long) test objects.

The pulse typically has a risetime of 10 ns and a 1/e decay time of 350 ns. The decay time may be varied by changing the output switch pressure.

3.2.4.3 Administrative Data

The HEMPS facility is operated by the Army SAFEGUARD Communications Agency (SAFCA). Schedule and rental cost data can be obtained by contacting SAFCA.

3.2.4.4 Reference Information

More detailed information concerning the design and operation of the facility can be obtained from the following:

- "HEMPS Operations and Maintenance Manual", EG&G Report AL-645, October 1971.
- "Final Report, HEMPS Evaluation", EG&G Report AL-409, September 1970

3.2.5 TEFS

The TEFS Simulator (Transportable Electromagnetic Field Source) is a ground based transportable EMP simulator. It employs an array of aluminum wave launchers (horns) which are fed by multiple cables from a pulser which generates a double exponential pulse. The array of wave launchers can be erected horizontally to launch a vertically incident plane wave, or the launchers can be erected vertically to generate a horizontally incident plane wave. The wave launchers are assembled into modules which can be used in a variety of rectangular configurations with a resulting wide range in the dimensions of the TEFS array. The working volume for TEFS can be as large as 40 meters by 40 meters.

3.2.5.1 System Description

Figure 3.20 is a schematic view of a typical TEFS installation with the wave launchers (horns) erected horizontally to generate a vertically incident plane wave. The horns are supported on non-conductive supports not shown on the schematic. Wire side screens are shown in the schematic to guide the wave.

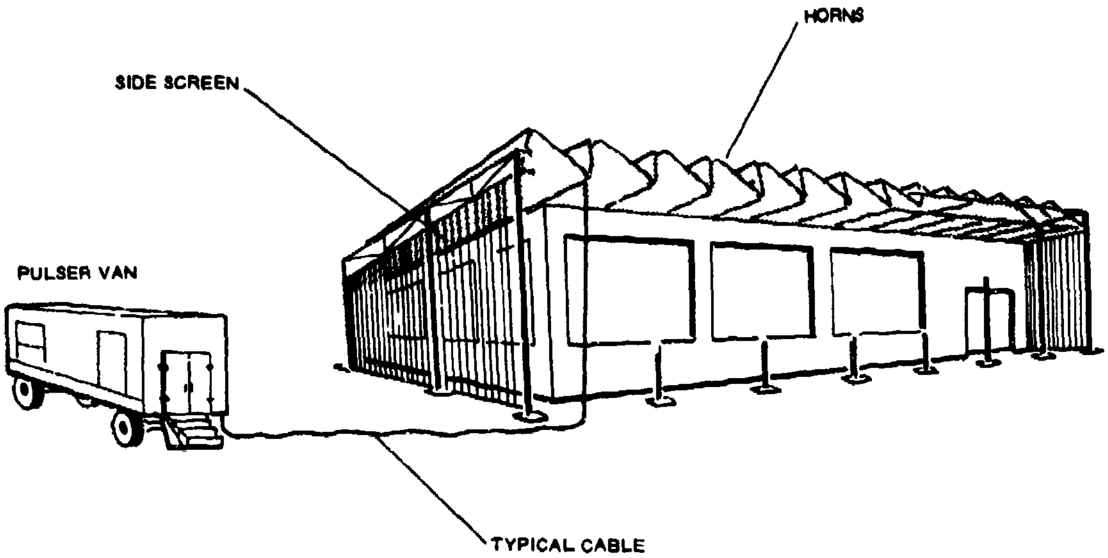


Figure 3.20 Schematic View of TEFS

The array is assembled from basic modules that are 3.36 meters by 3.36 meters. Each module consists of four horns with a nominal impedance of 200 ohms. The horns can also be used in a compressed configuration that is half as wide as the basic module.

The basic module dissassembles into components that stack neatly for shipping.

The TEFS array is driven by special gas-blocked RG-14 coaxial cables. Two-hundred fifty-six (256) cables are required to drive the full array. These cables are driven in parallel at the pulser end. At the array end, the feed cables are connected to a 50 ohm to 100 ohm tee with two 100 ohm outputs made from two 50 ohm cables. The two 100 ohm outputs each drive two 200 ohm horns in parallel.

Five pulser models have been developed by Radyne for use with the TEFS array. They are designated as the R-0, R-1, R1-A, R-3, and R-4 pulsers. Table 3-2 lists the important characteristics of these pulsers.

In the past, the Physics International T-7 pulser has been used with the TEFS array for testing large communication sites. This pulser was also used with a small TEFS array for testing mobile computing units. The T-7 consists of 6 simultaneously fired modules, one of which is shown in Figure 3.21. The 400 nf capacitors are charged in parallel and discharged in series through the 35 nf peaking capacitors. Forty-eight (48) 52 ohm output cables are connected to the output of each module. When the entire TEFS array is used, all six modules must be fired in order to pulse the 256 feed cables. For smaller TEFS arrays, only part of the 6 modules are necessary. The field levels are controlled by the charge voltage and the value of the attenuators (shown as R_s and R_p in Figure 3.21) feeding the output cables.

TABLE 3-2

THE RADYNE PULSERS

Model	No. Of Capacitors Per Quadrant	Max. Charge Voltage	Nominal Rise Time 10-90%	Approximate Delivery Date	Present Position	Special Characteristics
R-0	36 total	5 kV	12	01 Sept 1970	West Range	"Quarter Section Pulser" Special construction for low voltage operation. 36 cable outlets
R-1	1	15 kV	12	16 July 1970	West Range as R1-A	Well constructed. Used extensively for low voltage mapping
R-1A	1	7 kV	12	1970	West Range	Modified R-1 to allow use of single power supply
R-2	3	$\pm$ 30 kV	25	03 Sept 1970	Dismantled	First high voltage model. Used principally to obtain operating experience. Poor mechanically
R-3	4	$\pm$ 60 kV	20	06 Nov 1970	West Range	Tight mechanical tolerance. Used for all initial high voltage work
R-4	4	$> \pm$ 60 kV	10	28 Apr 1971	West Range	Basically as R-3, but with extensive mechanical and minor electrical improvements to give more reliability

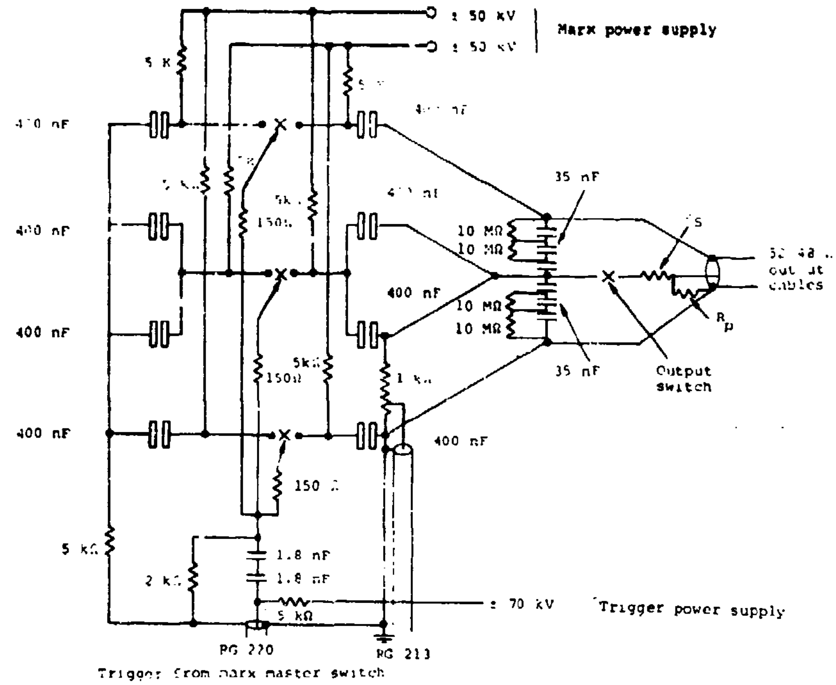


Figure 3.21 T-7 Pulser Module

3.2.5.2 Electromagnetic Characteristics

With the T-7 pulser, electric field strengths of 65 kilovolts per meter with a risetime of 15-20 ns and 1/e decay time of 300 ns can be generated. This risetime refers to the output of the T-7 and is often degraded by the array in reaching the working volume. The decay time may be either increased or decreased by varying the pulser's output switch pressure.

A special crowbar circuit in the T-7 prevents reradiated pulses (resulting from the pulse reflected from the array being reflected again at the pulser input) from exceeding 16% of the incident pulse.

3.2.5.3 Administrative Data

The TEFS system is owned and operated by the SAFEGUARD Communications Agency (SAFCA). The system is presently in storage at Fort Huachuca, Arizona. Information concerning availability of the system can be obtained by contacting SAFCA.

3.2.5.4 Reference Information

More detailed information concerning the design and operation of the system can be obtained from the following:

- "Final Test Report, New Hope, Ohio", EG&G Report AL-919, March 1973.

3.3 RADIATING SIMULATORS

The remaining simulators can be coarsely defined by the term "radiators". This term implies that the EM energy is not confined by the metallic topology of the simulator structure. Rather, the energy is in general terms radiated by the simulator in a manner analogous to classical antenna theory.

However, the term "radiator" does not apply exactly to all simulators to be described in this section. Antennas generating a vertically-polarized electric field are generally used such that the test object is in the far field region of the antenna pattern (fields fall off as r^{-1}); hence, the term "radiator" is proper. Some of the simulators designed to provide horizontally-polarized electric fields (e.g. HPD TEMPS, etc) are used with the test object in the near field region of the antenna where r^{-2} and r^{-3} terms are also present. For these simulators, the term "hybrid" is more descriptive since they have characteristics of both transmission line and radiating systems.

3.3.1 VPD

The Vertically Polarized Dipole (VPD) Simulation Facility was designed and erected by EG&G for the AFWL in 1971. The name Vertically Polarized Dipole is derived from the fact that the electric field radiated by the antenna is vertically polarized. The facility has been in use since early 1972 for the testing of airplanes and missile systems. The majority of the tests have been conducted on the B-52 airplane. The Hound-Dog (AGM-28) missile also has been tested both in the captive configuration (attached to the B-52 as it would be before launch) and in the free-flight mode. The free-flight mode included tests with the missile oriented horizontally (perpendicular to the electric field) and vertically (parallel to the electric field). The C-130 TACAMO airplane was tested briefly in this facility; a report of this test has been published.[1]

3.3.1.1 System Description

Figure 3.22 shows a site plan of the facility. The apex of the antenna (location of the pulser) is located 100 meters from the center of an airplane parking pad. A ground plane extends from under the antenna across the airplane parking pad. Near the pulser, the ground plane is formed of a 1/2-inch by 1/2-inch wire mesh. The wire mesh size is increased to 2-inches by 2-inches and then to 4-inches by 4-inches out to the perimeter of the antenna. Beyond the antenna and over the parking pad, the ground plane is formed of radial wires with cross-wires spaced at 10-foot intervals and soldered to the radial wires.

[1] Naval Ordnance Laboratory. *EMP Test and Evaluation Report of a TACAMO IVB Aircraft (U)*, by David C. Koury et al. Silver Spring, Md., NOL, December 1973. 605 pp. (NOLTR 73-227, Appendix J, publication SECRET RESTRICTED DATA, appendix unclassified.)

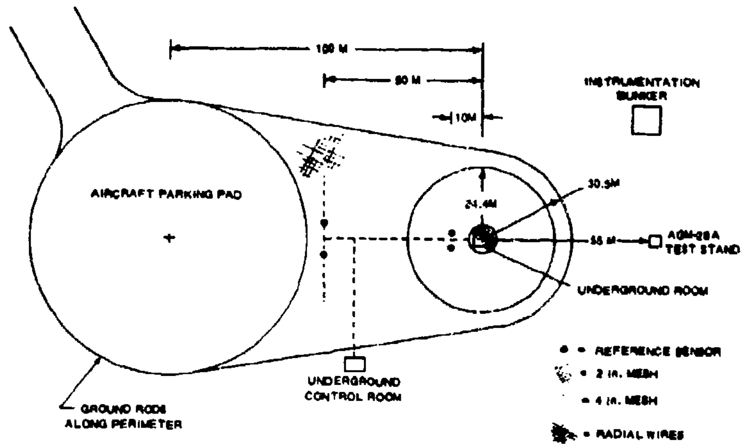


Figure 3.22 VPD Facility Site Plan

The two instrumentation rooms utilized at the facility are also shown in Figure 3.22. The main pulser control room is shown at the bottom of the chart. Conduits buried beneath the ground plane connect the pulser to the underground control room. Four reference sensors (two MGL B-dots and two HSD D-dots) are permanently located at distances of 10 and 50 meters from the antenna apex. The signal cables run through the conduit to the underground control room. Reference data for every pulse is recorded on oscilloscopes located in the control room.

A second bunker, shown in the upper right hand corner of Figure 3.22, was recently made an instrumentation room for the AGM-28 missile tests. The bunker includes a shielded room for data recording. A microwave telemetry system is used to transmit data from the test object to oscilloscopes.

Figure 3.23 shows a vertical profile of the antenna. The antenna rises to a height of 91 feet above the ground and is 160 feet in diameter at the top. The eight (8) primary wires of the antenna are resistively loaded to minimize reflection of the current pulse at the top of the antenna. The resistor values used are shown in Table 3-3. There are 13 resistor stations. The resistance value increases with height, in accordance with the equation shown in Figure 3.23. Modeling studies conducted before the antenna was constructed confirmed the effectiveness of the resistive loading, and actual field measurement data show that the radiated pulse closely approximates the desired double exponential pulse shape.

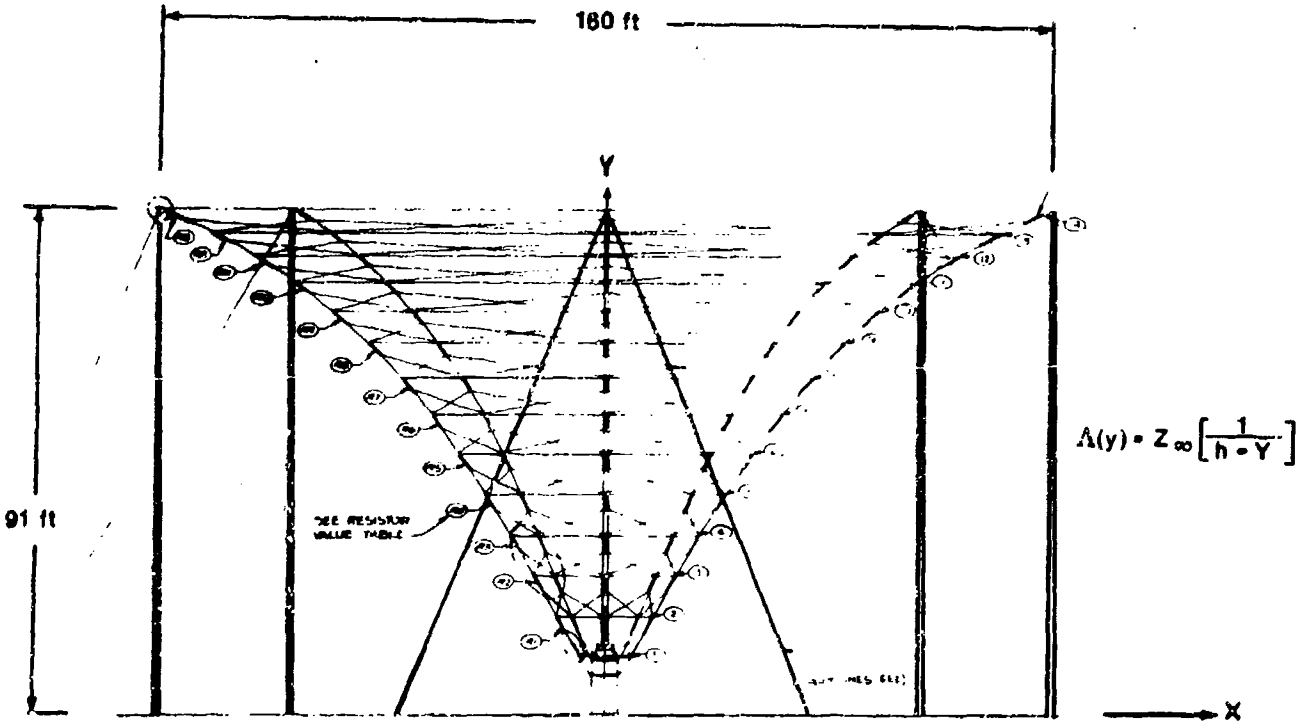


Figure 3.23 VPD Antenna and Resistor Locations

TABLE 3-3

VPD Antenna Coordinates and Resistor Values

COORDINATE TABLE		
	X	Y
1	4.500	10.600
2	8.600	17.700
3	13.009	25.130
4	17.410	32.560
5	21.827	39.990
6	26.432	47.300
7	31.355	54.400
8	36.810	61.100
9	42.722	67.400
10	49.033	73.300
11	55.777	78.700
12	62.961	83.500
13	70.511	87.700
14	78.319	91.398

RESISTOR VALUE		R_T
R1	103 OHMS	12.4
R2	112	14.0
R3	123	15.4
R4	138	17.3
R5	154	19.3
R6	175	21.9
R7	204	25.6
R8	260	32.5
R9	302	37.8
R10	399	49.9
R11	588	73.5
R12	1150	144.0
R13	3200	400.0

The antenna geometry is basically that of a cone. However, the cone is flared, that is, the diameter increases with height faster than that of a cone. The antenna shape would be a perfect cone were the antenna solid. In this case, the antenna impedance along the cone would be constant until the discontinuity at the top. However, since the antenna is not solid (for obvious reasons of practicality and cost) but rather formed from a rather sparse array of wires and resistors, the flaring compensates for the changing impedance. The cross wires and spider-web type top cap (not shown) were added to increase the antenna capacitance and thereby the low frequency content of the pulse.

The high-voltage pulser used in the VPD is one of two pulsers originally developed by Physics International for the AFWL several years ago for the helicopter-borne RES I Simulator. As modified, the pulser consists of a 16-stage, spiral configuration Marx generator which, when erected at full voltage, produces a pulse of about 1.6 MV across a water transfer capacitor (Figure 3.24). The transfer capacitor decreases the risetime of the radiated pulse. A self-breakdown, gas-insulated output gap is driven to about 1.8 MV.

The pulser includes an early-time bicone radiator which has an impedance of approximately 160 ohms, determined by the bicone angle

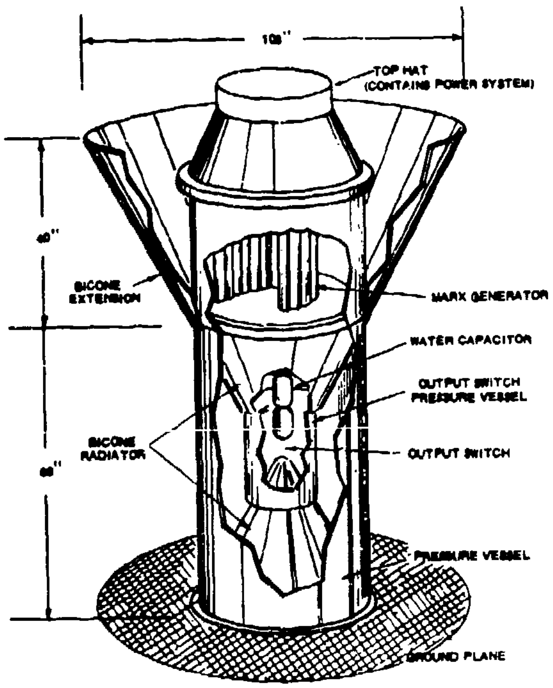


Figure 3.24
RES-I Pulser as Used in the Vertically Polarized Dipole

of 30.3°. For the VPD application, the lower half of the bicone is terminated at the ground plane; thus, there is an impedance discontinuity at this point. The impedance of the antenna/pulser system after this discontinuity is approximately 80 ohms.

The RES-type pulser is used in the RES, VPD, HPD and DRI simulators. The pulser design is described in more detail in a later section on the RES system.

3.3.1.2 Electromagnetic Characteristics

The fields radiated by the VPD have been measured on several occasions. Figure 3.25 illustrates the effectiveness of the resistive loading of the antenna and the existence of the near-field effects at the 100-meter test location. The data were recorded using an electric field sensor (HSD-2). The electric field has a peak strength of about 4 kV/m and shows a significant late-time, near-field component. The 100-meter test location is close enough to the antenna so that the near-field, which falls off as the inverse cube of the distance (r^{-3}) is seen.

Figure 3.25 is a computer plot of data formed by the numerical combination (time tieing) of oscilloscope traces. The oscilloscopes were operated on different time bases so that a much longer time period could be recorded. Therefore, greater accuracy was obtained in determining the late-time or low-frequency content of the pulse. As can be seen, the electric field lasts for about 10 microseconds. The RC decay time of this late-time field is determined by the product of the capacitance of the antenna (about two nanofarads) and the value of a $CuSO_4$ resistor placed across the bicone (about two kilohms).

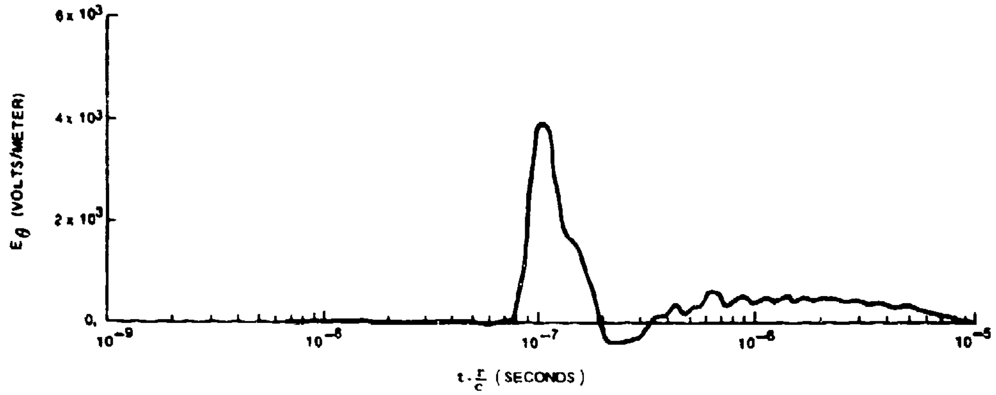


Figure 3.25
Electric Field Waveform at r = 100 m
and 3 m Height, Showing Late-Time Effects

Figure 3.26 shows the Fourier transform of the data shown in Figure 3.25. The late-time (low frequency) content of the electric field is illustrated by comparison to an ideal Hertzian dipole (far-field) prediction. At frequencies above about 5 MHz, the agreement between the far-field theory and the near-field experimental data is very good. At frequencies below about 2 MHz, late-time, low frequency energy in the field is clearly observable.

The fields radiated at distances fairly far away from the simulator were of concern, particularly since there are two parking pads used to off-load explosive within 850 meters of the antenna. The FAA control tower is also very close to the simulator (about 300 meters from the antenna apex). Therefore, some field mapping away from the simulator

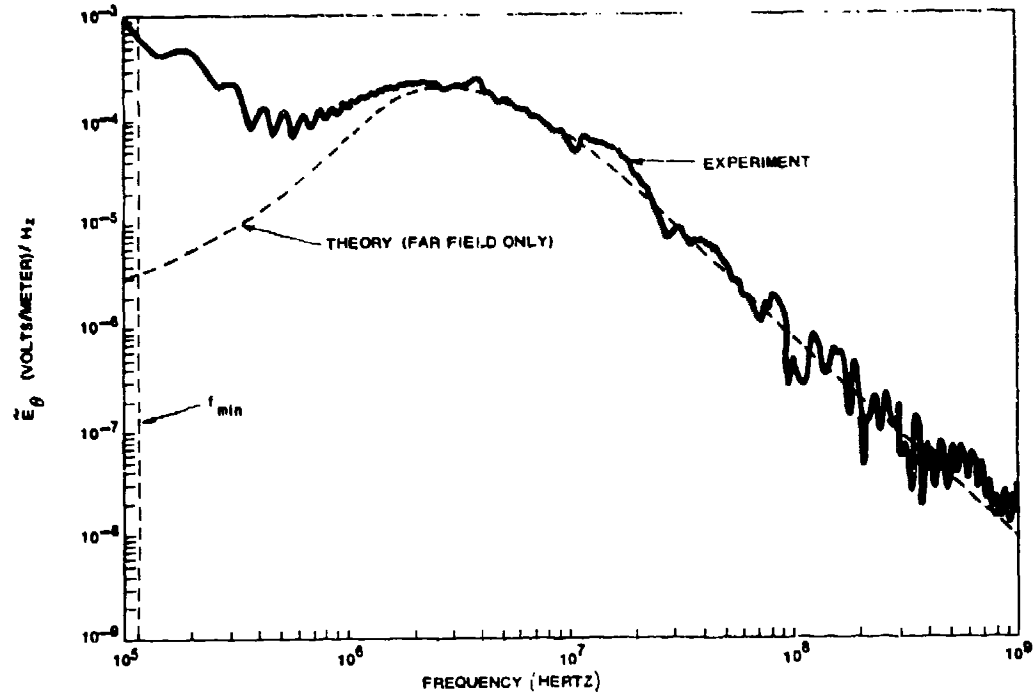


Figure 3.26 VPD Electric Field Spectrum (Measured vs Theory)

has been done. The field strengths shown in Figure 3.27 are expressed in volts/meter. However, these strengths were actually measured using a magnetic field sensor and then converted to equivalent electric field values using the far-field relationship $E = cB$. The measured values at the two parking pads are from two to four times lower than theoretical predictions, based on a perfectly conducting ground plane. The actual earth is finitely conducting and the effect is to cause losses in the higher frequencies (early time or peak-field) of the pulse.

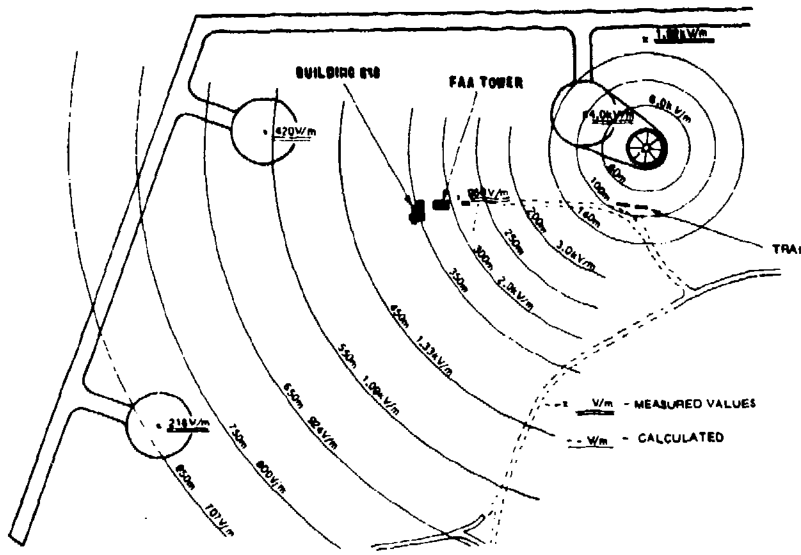


Figure 3.27 VPD Radiation Pattern

3.3.1.3 Administrative Data

The VPD facility is operated by the Air Force Weapons Laboratory. The AFWL Project Officer is:

Major Bruce Sanderson
AFWL/ELT
Kirtland AFB, New Mexico 87114
Telephone: 505-247-1711, extension 2896

Testing of an FB-111 airplane is scheduled in late 1974 or early 1975. Based on past experience, facility rental costs are estimated to be about $10,000 per month assuming a standard single-shift, 5-day-week operation. The user would pay all costs actually incurred during a test.

Further information regarding facility scheduling or rental costs should be obtained through AFWL/ELT.

3.3.1.4 Reference Information

More detailed information concerning the VPD design or operation can be obtained from the following:

- "Final Report, Vertically-Polarized Dipole Evaluation", EG&G Report AL-685, March 1972.
- "Vertically-Polarized Dipole Transfer Function Capability", EG&G Report AL-949, July 1973.
- "EMP Simulation Facilities for Aeronautical Systems EMP Program", June 1972 (can be obtained from AFWL).

3.3.2 DRI Simulator

The 2 MV pulsed antenna system of the Denver Research Institute (DRI) has been used mainly for the study of electromagnetic propagation in the presence of metallic objects. The large ground plane and availability of instrumentation, however, make the Colorado facility suitable for EMP tests also. The simulator provides only vertically polarized electric fields; however, it is estimated that the pulser could be raised 50 feet above the ground and operated in the horizontal mode for a construction cost of $15,000.

3.3.2.1 System Description

The DRI pulsed antenna system used to provide the source test function is a Marx generator, biconic antenna combination operated in the vertical mode. The Marx generator consists of 32 $0.01\mu F$ capacitors charged to a potential of 45 kV. These are then discharged into the antenna in series giving a source voltage at the antenna of 1.44 MV. This source is basically a Physics International RES pulser which has been modified by DRI. The simulator was modified to eliminate as much of the lower bicone as possible. Ideally, the feed-point, which is a pressurized spark gap, would be composed of the radiating antenna element and a flat ground plane.

Because of the main gap configuration, this was not completely realizable. However, the major portion of the bottom cone was removed and a ground plane installed, which left an effective bottom cone of about 12 inches.

The simulator is installed in a 36 inch deep pit which allowed the addition of an essentially flat ground plane in the immediate vicinity. The simulator modification and installation were important factors in the generation of a radiation pattern that was well behaved both in azimuth and elevation.

The simulator's ground plane covers a 125° sector, 363 meters in radius and consists of wires placed on the ground at 3° increments. This area is completely clear of buildings and obstructions and therefore provides a high degree of field uniformity. The simulator design, with the pulser's ground electrode at the same level as the ground plane, eliminates reflections from the bottom half of the bicone. The late time antenna consists of a 12-wire conical extension 88 feet in length. The antenna is not resistively loaded.

3.3.2.2 Electromagnetic Characteristics

The simulator output, as recorded on a Tektronix 7903 scope, has a 1 ns risetime and a 0 crossing at 20-30 ns. Precise field levels for the simulator are not known; however, good estimates may be obtained by extrapolating from the peak 500 kV/m level at 1 m from the bicone.

3.3.2.3 Administrative Data

The simulator is operated by the Denver Reserach Institute Schedule and rental cost information can be obtained by contacting:

Mr. Fred Vinditti
Telephone: 303-753-2241

3.3.2.4 Reference Information

More detailed information about the DRI simulator can be obtained from the following:

- "2.0-Megavolt Pulse Antenna System", Physics International Report PIMM-280, January 1971.

3.3.3 RES I

The Radiating EMP Simulator (RES) program was initiated by AFWL in the spring of 1967 to develop a flyable simulator for fixed site and airplane vulnerability assessment. The program has steadily progressed since 1967, and has resulted in the development of both horizontally and vertically-polarized radiating antenna systems. The two RES-I systems, horizontal and vertical, can be used to make coupling measurements on in-flight test airplanes for both horizontally and vertically polarized E-fields.

The RES system has been used to test Minuteman missile silos, ground based communications facilities, and an in-flight C-130 (TACAMO) airplane. A report of the TACAMO test has been published.[1]

[1] Naval Ordnance Laboratory. *EMP Test and Evaluation Report of a TACAMO IVB Aircraft (U)*, by David C. Koury et al. Silver Spring, Md., NOL, December 1973. 605 pp. (NOLTR 73-227, publication SECRET RESTRICTED DATA.)

3.3.3.1 System Description

The horizontal antenna system is composed of a pulser and an inflated antenna structure, which uses a CH-47 helicopter for system mobility. The 200-foot long antenna is a fiberglas structure, which maintains its shape by inflation to 4.2 psig. This horizontal system delivers an EM pulse of at least 900 V/m at 500 meters.

The vertical antenna system uses the same pulser as above and a wire-cage antenna. It uses either CH-53 or CH-47 helicopters for system mobility. The pulser has a biconic section, with a self-breakdown switch located at the apex. It is capable of 1.75 MV output. The antenna is approximately 200 feet long, and the pulser-antenna combination produces a pulse similar, except for polarization, to that produced by the horizontal system.

The RES-I pulser assembly consists of the following primary components: 1) power system, 2) Marx generator, 3) inductor, 4) transfer capacitor, 5) output switch, and 6) pressure vessel. Each of these components and/or subsystems is described in the following paragraphs.

Power System

The power system's source is a standard airplane, wet-cell battery. The battery is connected to a dc to ac (24 Vdc to 110 Vac) inverter which supplies the power to the ±30 to ±50 kV Marx generator power supply. The gas is used as a dielectric, avoiding the additional weight of solid insulations. A standard quadrupler circuit is utilized in the generator's power supply.

An overvoltage circuit controls the output of the high-voltage power supply. A metered control on the regulator is used to adjust the voltage to any desired level up to ±50 kV. The Marx generator requires approximately 30 seconds to charge to this value.

Marx Generator

Figure 3.28 shows the Marx generator circuit. A spiral Marx configuration was used, as this geometry offers self-shielding of the high voltages. Each stage of the generator consists of two, 0.1 μF (at 50 kV) capacitors. Stage capacitance is then 0.05 μF at 100 kV. The stored energy per stage is:

$$U_s = 1/2\, CV^2 = 1/2\, (0.05\,\mu F)\ (100\,kV)^2$$

$$= 0.05\,(5 \times 10^3)\ J = 250\,J$$

There are 15-1/2 stages,* the first consisting of one capacitor connected to ground (the metal cone). The total stored energy is:

$$U_s = 15.5\,(250) \approx 3900\,J$$

Figure 3.28 also shows the charging resistors which isolate each stage from its neighbors by producing an RC time for each stage that is long compared to output pulse duration. The Marx generator output is

* The units recently have been modified by AFWL to include 16 stages.

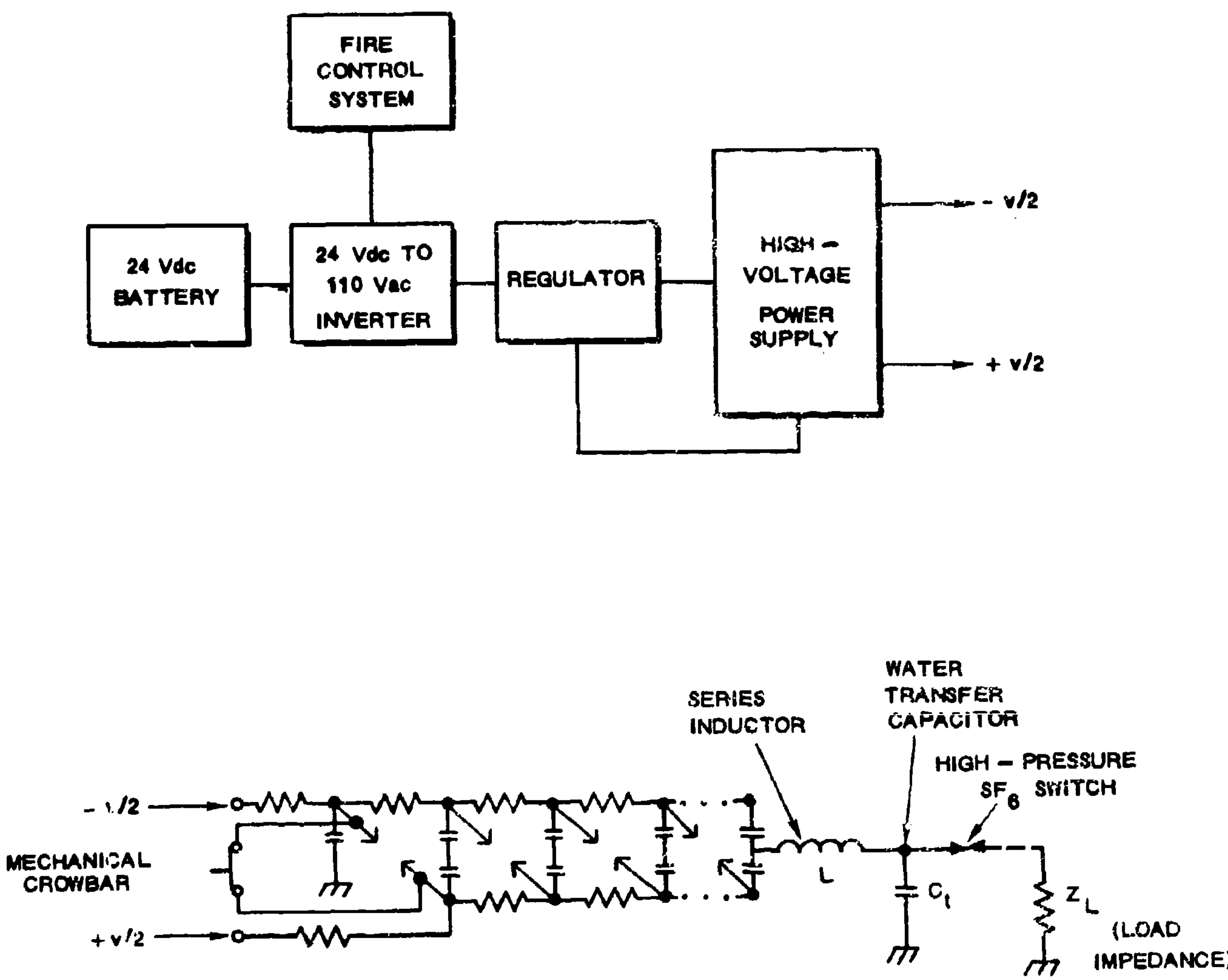


Figure 3.28 RES-I Pulse Generator Electrical Subsystems

connected to an oil-filled (dielectric) inductor by two spark gaps. The inductor provides energy transfer efficiency and permits the generator to be short-circuited repeatedly without damage to its capacitors. Each stage has an inductance of approximately 3.5 μH while the lumped inductance value is approximately 150 μ H. The inductor is connected to the center conductor of the water transfer capacitor, the fast risetime element of the system. The Marx generator charges the water capacitor in about 1.2 μs with a waveform similar to that shown in Figure 3.29.

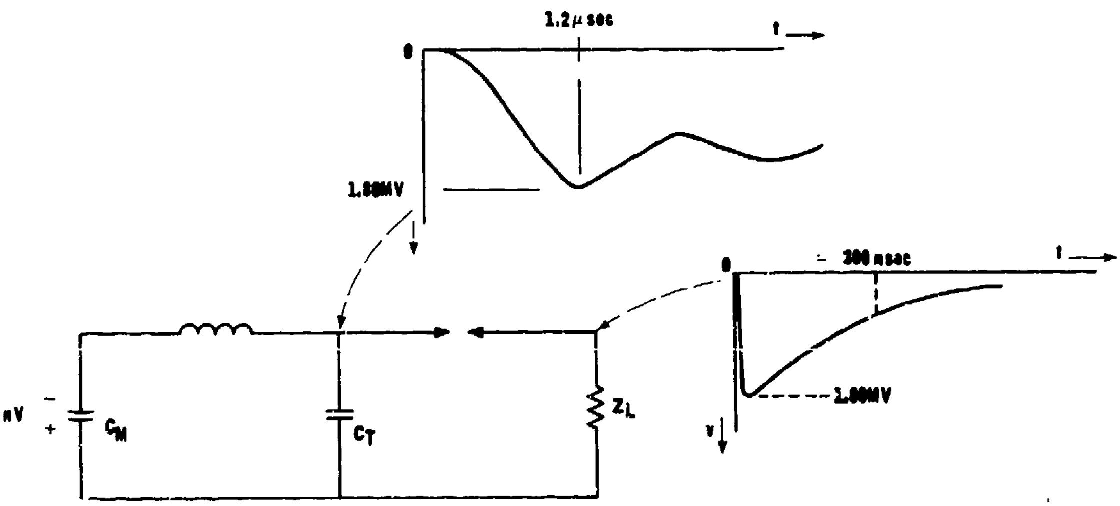


Figure 3.29 Voltage Waveforms

The output switch, connecting the water capacitor to the antenna structure, is a high pressure ($\approx$100 psig) SF_6 gap. At or near the peak charging voltage, the switch self-fires, discharging the capacitor into the antenna. Breakdown voltage is dependent upon the switch pressure.

3.3.3.2 Electromagnetic Characteristics

The RFS-I antenna design is based on the requirement for a radiation pattern similar to that produced by a dipole, one with symmetry about both the major and minor axes of the system. The antenna is comprised of a biconic high-frequency wave launcher and a long low-frequency radiating antenna.

Biconic Antenna

In the area of the pulser, the design of the antenna is biconic, as shown in Figure 3.30. This geometry radiates the high-frequencies of, the system. It has been shown that the peak E-field magnitude on the equatorial plane is:

$$E_{pk} = \frac{60V_o}{rZ_k}$$

where E_{pk} is the magnitude of the peak E-field, V_o is the driving voltage, r is the radial distance to the point of observation, and Z_k is the biconic impedance given by

$$Z_k = 120\,(\ln \cot \theta_{hc}/2).$$

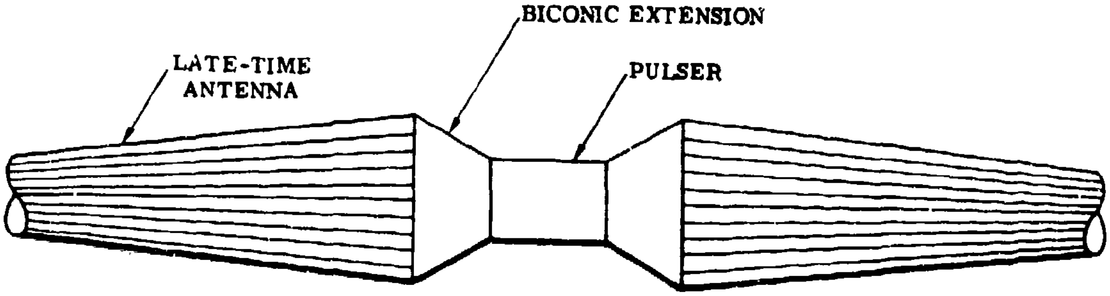


Figure 3.30 Pulser Antenna System

The value θ_{hc} is defined in Figure 3.31. The above expressions assume the pulse risetime to be instantaneous. For rise-times that are not instantaneous the peak field is radiated if the biconic slant height exceeds a certain minimum length.

For this pulser,

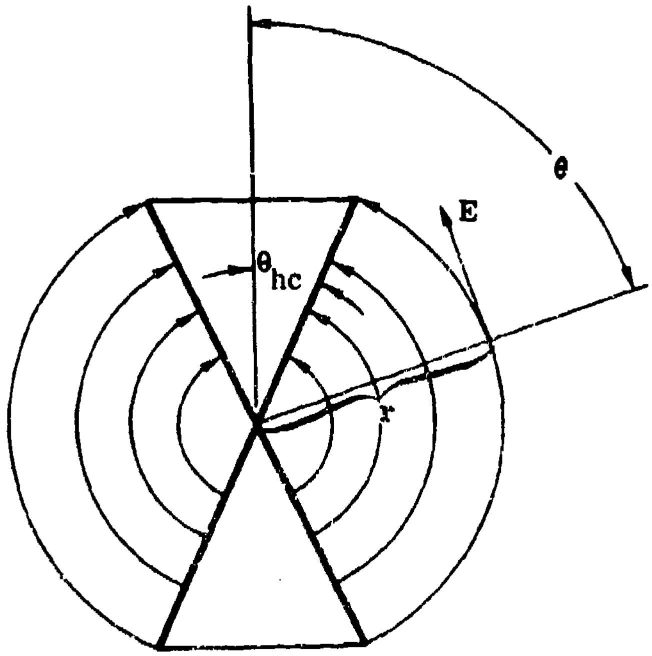
$$\theta_{hc} \approx 30 \text{ degrees.}$$

Therefore,

$$Z_k \approx 160\,\Omega \text{ and}$$

$$E_{pk} \approx 1.3 \text{ kV/m at 500 m}$$

(assuming the maximum V_o of 1.75 MV).



$$Z_k = \frac{Z_o}{\pi\sqrt{\epsilon_r}}\, \ell n \cot \frac{\theta_{hc}}{2}$$

$$E = \frac{60\ V_o}{r \sin\theta\, Z_k}$$

Figure 3.31 Biconic Transmission Line

In practice, one obtains a peak E-field of only 900-1000 V/m at b = 500 m. This reduction from the theoretical peak field strength is due to the impedance mismatch and resulting reflections at the bicone late time antenna junction.

Figures 3.32 and 3.33 show time and frequency domain plots of a typical RES pulse. The $\dot{B}$ sensor was located 500 m from the source and the pulser-probe line made a 10° angle with the ground plane. The peak magnetic field was 5×10^{-6} tesla or an electric field of 1.5 kV/m. (The data as illustrated has been corrected for ground reflections and angle of incidence.) After peak, the slope of the radiated pulse is determined by the design of the long antenna sections. For a simple non-resistively loaded dipole

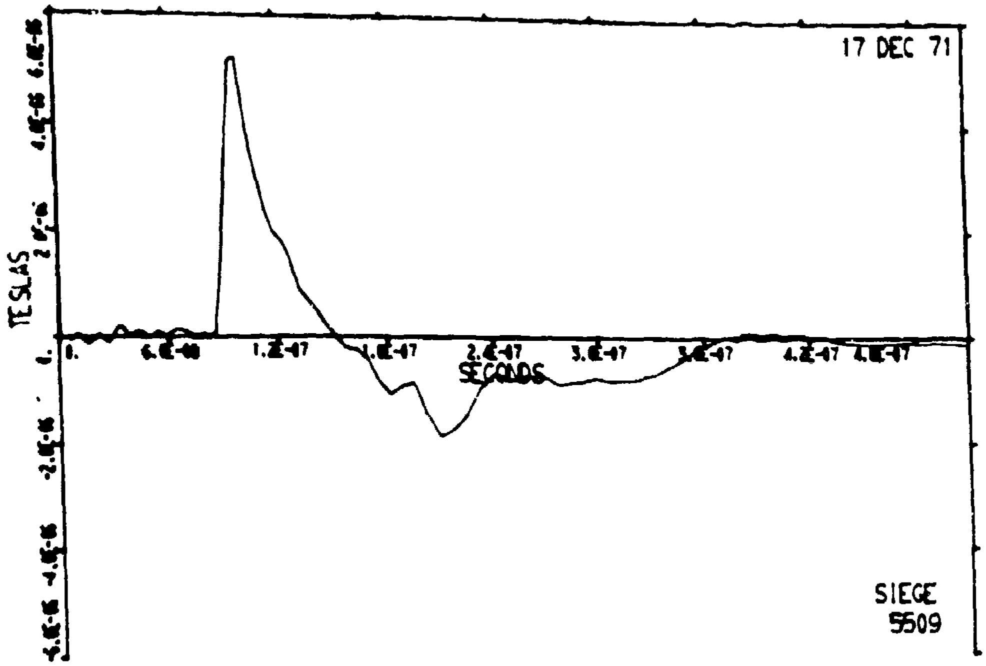


Figure 3.32 RES Pulse Time Domain

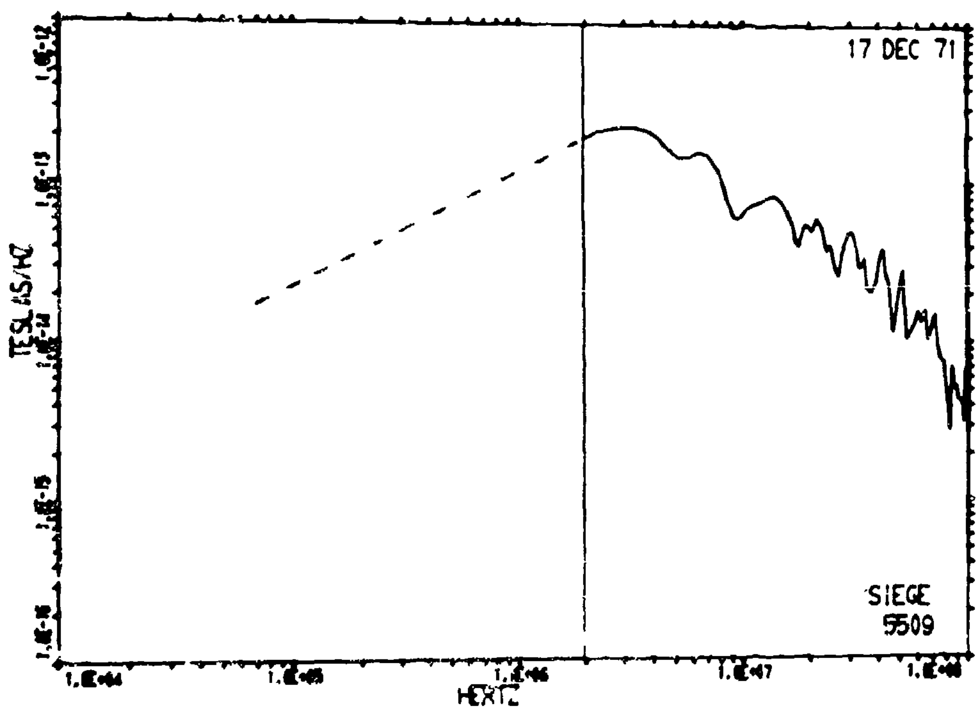


Figure 3.33 RES Pulse Frequency Domain

antenna, the length of this pulse, beyond which undershoot occurs, is equal to the antenna half-length. For this antenna, L is 100 ft., and the pulse length to the first zero crossing should be 100 ns at the equatorial plane. Since the antenna is resistively loaded, a somewhat shorter time should be anticipated. In Figure 3.33, the pulse width is about 70 ns.

For the vertical antenna system, resistors are placed on the ends of the antennas to reduce the current to zero before the initial wave arrives at these points. The radiated waveform is then shaped and damped and the outward flowing current is reduced in steps. Subsequent reflections are however, spread in space and time.

For the horizontal antenna system, lumped resistors are located at points along the antennas. The objective here is to damp the oscillitory nature of the fat-dipole radiation.

3.3.3.3 Administrative Data

The RES is maintained and operated by the Air Force Weapons Laboratory. The AFWL Project Officer is:

Major Bruce Sanderson
AFWL/ELT
Kirtland AFB, New Mexico 87114
Telephone: 505-247-1711, extension 2896

The RES is presently scheduled for a two month Minuteman test in the spring of 1975. Rental costs for the simulator have averaged $10,000 per week. The cost is based on a standard single-shift five day week operation lasting six weeks. Since this cost includes mobilization and demobilization expenses, the costs for tests of other durations would not scale linearly with the six week figure. For detailed cost and schedule information, the interested party should contact the Air Force Weapons Laboratory/ELT.

3.3.3.4 Reference Information

For more detailed information about the RES design and operation, the following sources can be consulted:

- "Acceptance Test Program, Radiating Electromagnetic Pulse Simulator (RES-I)", EG&G Report AL-453, August 1970.
- "Development of an Airborne Pulsed Antenna System", AFWL-TR-70-162, January 1971.
- "Final Report, High-Altitude Generator Modification, HAG-IA Pulser", EG&G Report AL-572, May 1971.
- "Electromagnetic Pulse Handbook For Missiles and Aircraft In Flight", SC-M-710346, September 1971, Sandia Laboratories.

3.3.4 Suspended RES

The Suspended RES dipole was designed and constructed for the AFWL by EG&G in 1973. At present, field mapping tests of the simulator are being completed. Recently the 747 Command Post was tested with the facility.

3.3.4.1 System Description

The simulator is shown in Figure 3.34 below. The simulator is located at Kirtland AFB adjacent to the VPD facility described earlier. The two simulators use a common parking pad for the test airplane.

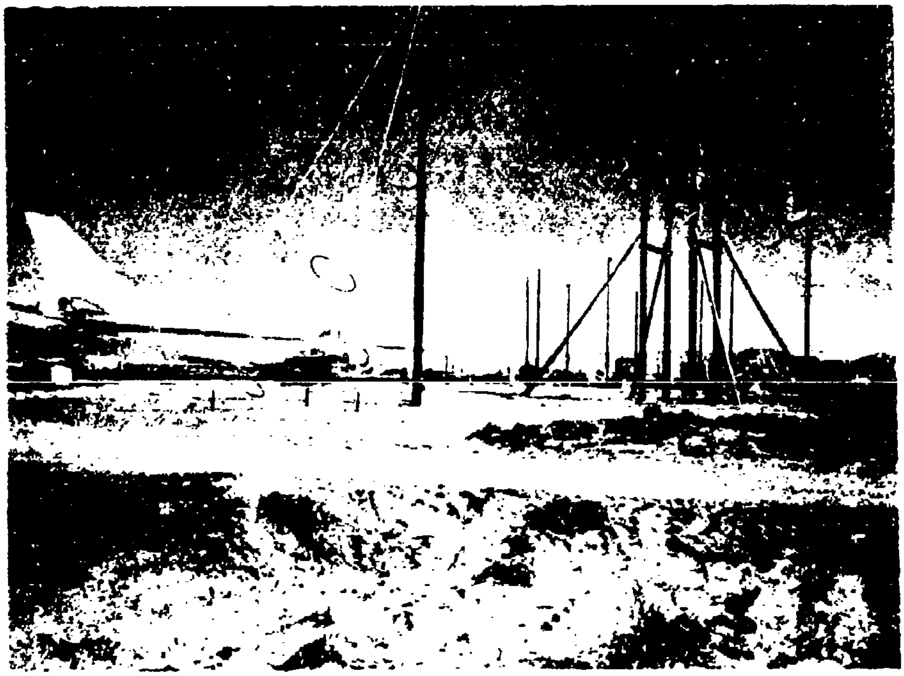


Figure 3.34 The Suspended RES Antenna System

The antenna is a resistively-loaded, 9 foot diameter circular section dipole which projects 95 feet horizontally from each side of the pulser. The antenna then slants downward at a 55° angle to the ground level. The antenna is supported by two poles with dielectric rope. The entire apparatus can be lowered to the ground with a winch system. In its test configuration, the antenna is 70 feet above the ground. The antenna system has the following characteristics:

a) Twelve (12) sections, six (6) per each side of the pulser.

b) Ten (10) parallel wires per section, assembled in a circular pattern, 9 feet in diameter.

c) The resistors range in value from 450 to 464 to 478 ohms.

The antenna was fabricated from available Dale NS-10 wire-wound resistors that were both coated and uncoated. With these available resistors, the object was to make them as alike as possible, while maintaining a consistent number of resistors per string so that the length of the fabricated sections would be uniform and, therefore, facilitate antenna design.

The power source for the simulator is a RES-I pulser. A discussion of this pulser's operation is given in the earlier section on the RES. The pulser is suspended from four (4) telephone poles which are located 210 feet from the center of the parking pad.

The Suspended RES generates predominately a horizontally-polarized electric field. The simulator falls in the hybrid class discussed earlier.

3.3.4.2 Electromagnetic Characteristics

Figure 3.35 shows a typical time domain waveform of the Suspended RES antenna as measured above the center of the test pad. The pulse has a 10% - 90% risetime of about 5 ns and decays to zero amplitude in 16 ns. An undershoot of about 25% of the peak value occurs at later times, the pulse decaying to essentially zero in about 100 ns. The peak value of the pulse illustrated is 16×10^{-6} tesla, corresponding to an electric field of 4.8 kV/m. The maximum field strength attainable with the simulator is approximately 7 kV/m at a distance of 54 m from the pulser.

Figure 3.36 shows the Fourier Transform of the pulse illustrated in Figure 3.35. The figure shows that the pulse contains peak energy content at about 20 MHz. The frequency spectrum drops off sharply after 70 MHz.

3.3.4.3 Administrative Data

The Suspended RES is maintained and operated by the Air Force Weapons Laboratory. The AFWL Project Officer is:

Major Bruce Sanderson
AFWL/ELT
Kirtland AFB, New Mexico 87114
Telephone: 505-247-1711, extension 2896

The simulator is immediately available for EMP testing. Rental costs for the facility are difficult to estimate since to date, only one test has been conducted. For a 5 day week, single-shift operation, the costs would be about $10,000 per month. The user would pay all costs

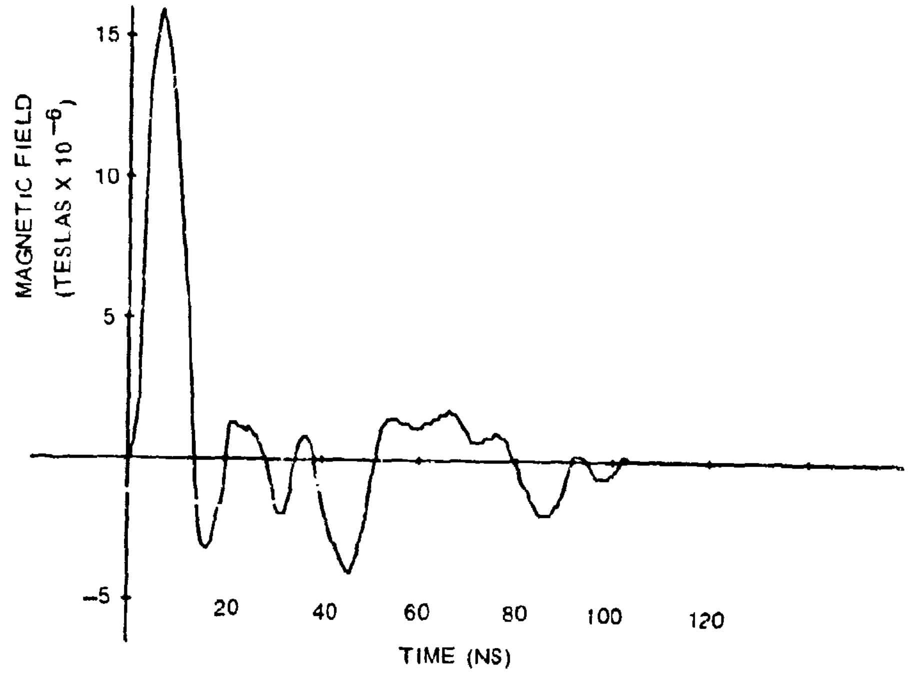


Figure 3.35 Suspended RES Pulse

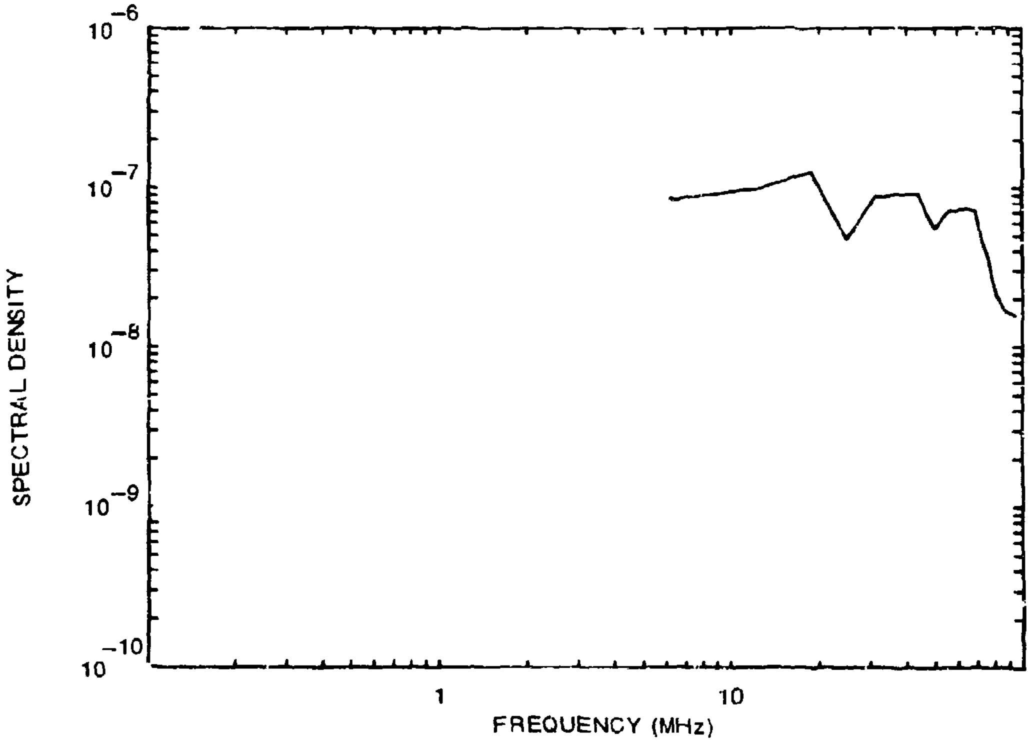


Figure 3.36 Spectrum of Suspended RES Pulse

incurred during testing. For more detailed cost and schedule information, the interested party should contact AFWL/ELT.

3.3.4.4 Reference Information

For more detailed information concerning the Suspended RES, consult the following:

- "Final Report; Design, Construction, and Field Installation of The Suspended RES", EG&G Report AL-1001, October 1973.

3.3.5 EMPRESS

The EMPRESS (Electromagnetic Pulse Radiation Environment Simulator for Ships) is a subthreat level simulator designed and constructed by IIT Research Institute for the Naval Ordnance Laboratory. This simulator was developed to provide the Navy with a test facility for performing coupling studies of electrical/electronic systems aboard ships. The general requirements were that the facility should be capable of illuminating a ship (DLG class or smaller), provide either a vertically polarized or horizontally polarized pulse, and produce an electromagnetic pulse which includes both the high frequency and low frequency components of interest.

Therefore, the EMPRESS was designed and constructed as a hybrid facility with both a horizontally polarized mode and a vertically polarized mode. The facility is located at Solomons, Maryland (re Figure 3.37), and is presently operational. The site was selected on the basis of providing the required physical characteristics, a deep water channel, and for its proximity to the Naval Ordnance Laboratory. Figure 3.38 is a photograph of the EMPRESS facility in its test configuration.

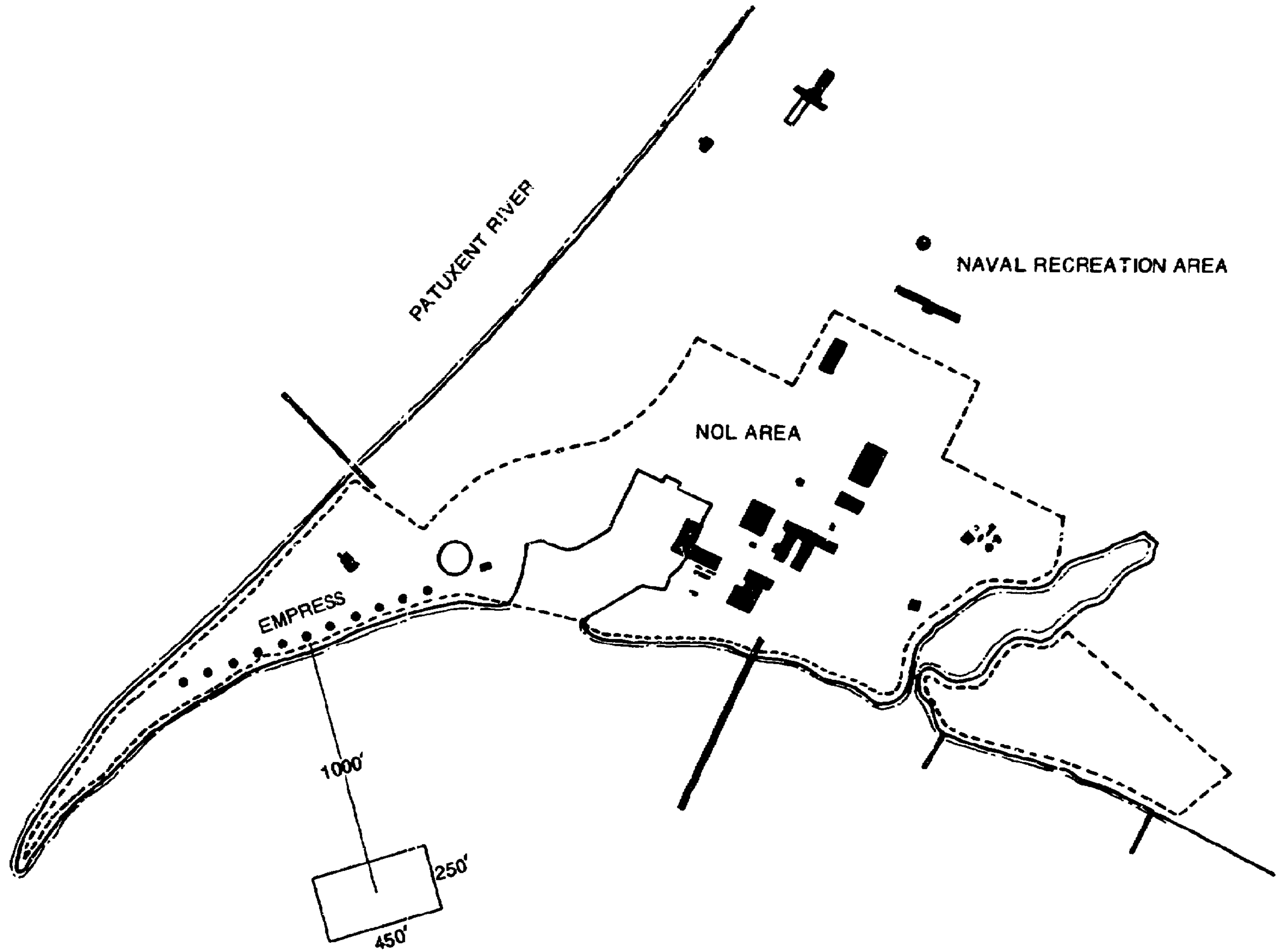


Figure 3.37
Location of EMPRESS and Ship Test Area At Solomons Branch, Field Division No., Solomons, Maryland

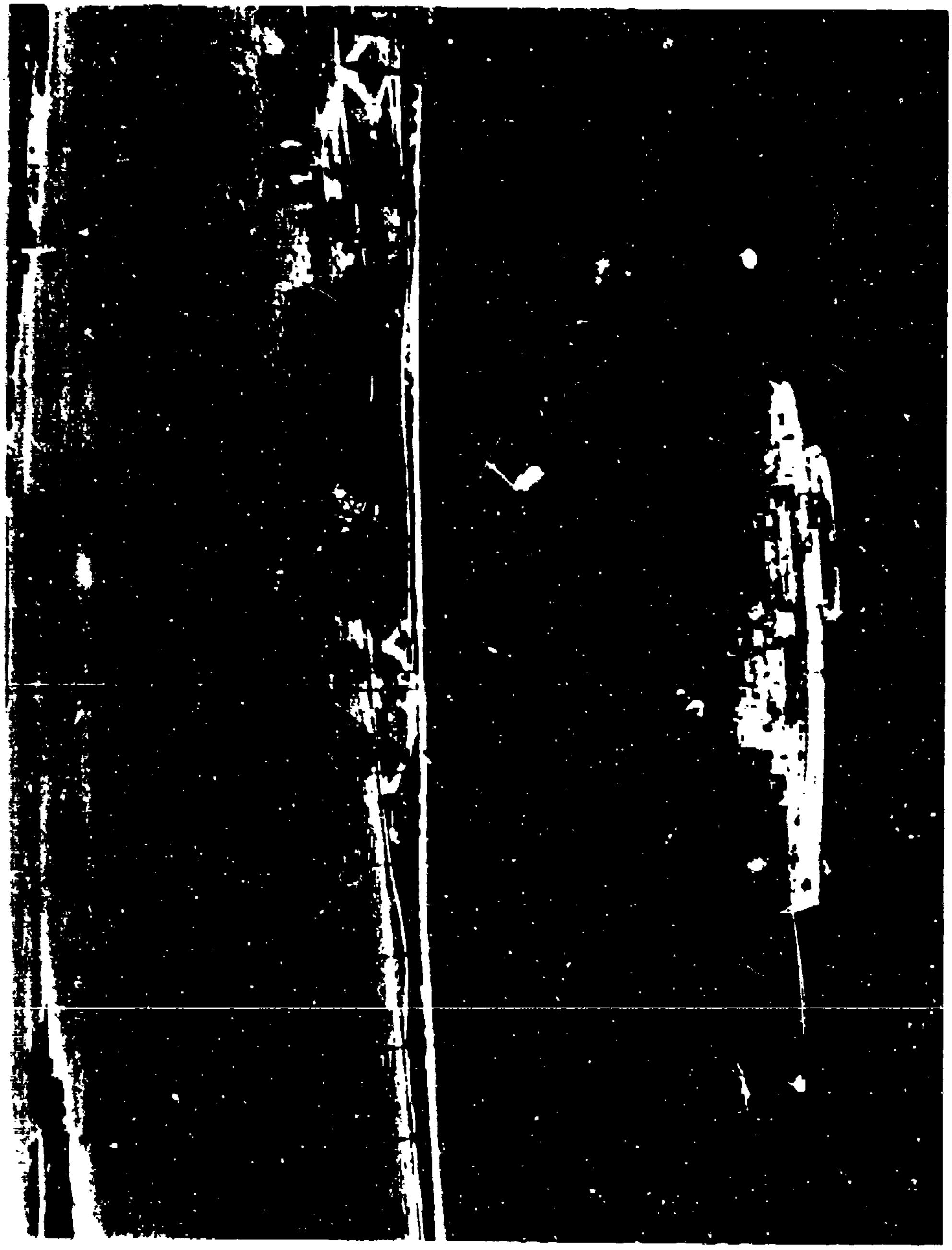


Figure 3.38 EMPRESS Test Configuration

Although the facility is primarily for subthreat level coupling studies of ships, it can and has been used for aircraft fly-by tests and near threat level testing of small subsystems by locating the subsystems close to the facility (i.e., within 50 meters).

3.3.5.1 System Description

The EMPRESS is a hybrid facility with both a horizontally polarized mode and a vertically polarized mode. The facility employs a 2.5 MV distributed peaking capacitor source (PULSPAK-8000) designed and developed by Pulsar Associates, Inc. Both the antenna facility and the pulse source can be converted from the horizontal to vertical mode or vice versa by 3 men in 2 days.

The horizontal mode of EMPRESS is a terminated biconic/dipole antenna structure similar to those discussed in other sections. This mode basically consists of a 1300-foot long, 9-foot diameter, 100-foot high horizontal dipole, center driven by the biconic mode of the PULSPAK-8000 and terminated at each end by a high voltage termination. The biconic section provides the fast rise or high frequency content of the radiated pulse and the terminated dipole extension provides the long time or low frequency content and minimizes the ringing or oscillation. The antenna and pulser are raised and lowered by electric winches.

The vertical mode of EMPRESS basically consists of a 100-foot high, 30-degree half-angle conical antenna, top loaded by the 1300-foot long horizontal line. In this mode, the mono-conic mode of the PULSPAK-8000 is used to drive the base of the conical antenna and the far end of the top loading horizontal line is terminated by a high voltage termination. The conical antenna provides the fast rise or high frequency content of the radiated pulse and the terminated top loading horizontal line provides the long time or low frequency content and minimizes the ringing or oscillations.

Pulser and antenna data are summarized in Tables 3-4 and 3-5, respectively, and are also discussed in the following paragraphs.

Pulse Generator

The facility employs a 2.5 MV distributed peaking capacitor source (PULSPAK-8000) designed and developed by Pulsar Associates, Inc. The PULSPAK-8000 is a highly reliable 2.5 MV distributed peaking capacitor source capable of operating either as a mono-conic pulser for the vertical mode or as a bi-conic pulser for the horizontal mode. This pulser employs a relatively high inductance 50 stage Marx generator charged to a maximum of $\pm$25 kV, has a total output capacitance of 4 nf, and a maximum stored energy of 12.5 kJ. Because of the relatively high inductance of the Marx and the resulting required peaking capacitance, the precursor or pre-pulse is less than 5% of the peak output voltage for both modes.

In the vertical or mono-conic mode, where the pulser must drive an early time impedance of approximately 75 ohms, the output pulse has a 10-90% risetime of approximately 8 ns. In the horizontal or bi-conic mode, where the pulser must drive an early time impedance of approximately 150 ohms, the output pulse has a 10-90% risetime of approximately 4 ns.

Although the pulser is capable and has been operated at its maximum output of 2.5 MV, it is normally operated at a reduced level to extend its life. Unless the test program requires other conditions, the PULSPAK-8000 is normally operated at $\pm$17.5 kV charge voltage with 74 psi of SF_6 in the main gap, resulting in an exponentially rising and falling output pulse with a peak voltage of 1.75 MV.

TABLE 3-4

Pulser Data

Physical Size	2.8 meter diameter 2.85 meters high 3,000 pounds
Voltage Output	0.5-2.5 megavolts
Energy Output	8 kilojoules @ 2 MV
Output Pulse Risetimes	6 nanoseconds -- monocone 8 nanoseconds -- bicone
Environmental	-40°F to +150°F (storage) 10°F to 150°F (operating) 95% humidity

TABLE 3-5

Antenna Data

Height	28 meters
Impedance	75 ohms
Cone Half Angle	32°
Ground Plane	Radius of 21.4 meters composed of 40 wires of number 12 copperweld
Environment	125 mph wind (no ice) 100 mph wind (1/4 inch ice load)

Fringe Field Line Data

Height	30.5 meters
Length	380 meters
Diameter	2.75 meter wire cage consisting of 18 wires
Terminations	300 ohms to ground
Environment	40 mph wind (raised, no ice) 125 mph wind (lowered, no ice)

Instrumentation

A 2.5 MV resistive divider is available to monitor the output voltage of the pulser. Further, both B-dot and D-dot sensors are used to monitor local environment data. Coupled transients are monitored using clamp-on current probes and/or differential voltage probes. The primary data recording instrumentation are Tektronix 454A oscilloscopes/cameras located in shielded scope boxes and powered by batteries and inverters. If required, the photographic data are digitized by a Graf-pen digitizer and processed on a digital computer.

3.3.5.2 Electromagnetic Characteristics

Although this facility is primarily for subthreat level coupling studies of ships, it has been used for aircraft fly-by tests and near threat level testing of small subsystems by locating the subsystem close to the facility (i.e., within 50 meters). Therefore, fairly extensive field mapping has been performed close to the facility and at distances fairly far away from the facility. Furthermore, this field mapping has included airborne mapping at altitudes up to 600 meters for the horizontal mode. Since the horizontal and vertical modes are essentially independent and have significantly different electromagnetic characteristics, they are discussed separately below.

Horizontal Mode

As stated previously, the horizontal mode of EMPRESS basically consists of a 1300-foot long, 9-foot diameter, 100-foot high horizontal dipole, center driven by the PULSPAK-8000 and terminated at each end by a high voltage termination. Since the antenna is located near earth, the time history and resulting frequency spectrum of the field at any point depends upon both the direct and reflected wave.

Assuming perfect reflection at the ground, the total field at any point sufficiently far from the antenna, where the $1/r$ variation due to path length difference is not significant ($r >> Tc$), is given by:

$$E(t) = E_o(t) - E_o(t - T) \tag{1}$$

where $E_o(t)$ is the direct wave at that point and T is the time delay between the direct and reflected waves. Employing the coordinate system shown in Figure 3.39 and assuming a point source located at the center of the pulser, it is easy to show that for points sufficiently far away from the antenna ($\rho^2 + z^2 >> h^2$), the time delay is given by:

$$T = \left(\frac{2h}{c}\right) \cos\theta \qquad \{(\rho^2 + z^2) >> h^2\} \tag{2}$$

where c is the speed of light and θ is the polar angle.

From this equation, it is easily noted that for points close to the earth ($\theta \approx 90°$), the time delay is very small and the resulting total field will be a very narrow pulse. Furthermore, for any fixed radial distance, the time delay or pulse width increases with increasing altitude. Finally, it should be noted that for points sufficiently close to earth, the time delay will be less than the risetime of the direct wave and the peak value of the total field will be less than the peak value of the direct wave. Therefore, for any fixed radial distance, the peak value of the total field will increase with increasing altitude until the time delay is greater than the risetime of the direct wave.

From Equation (1), it immediately follows that the frequency spectrum of the total field is given by:

$$\begin{aligned} E(j\omega) &= \int_{-\infty}^{\infty} [E_D(t) - E_D(t - T)]\, e^{-j\omega t} dt \\ &= [1 - e^{-j\omega T}]\, E_D(j\omega) \end{aligned} \tag{3}$$

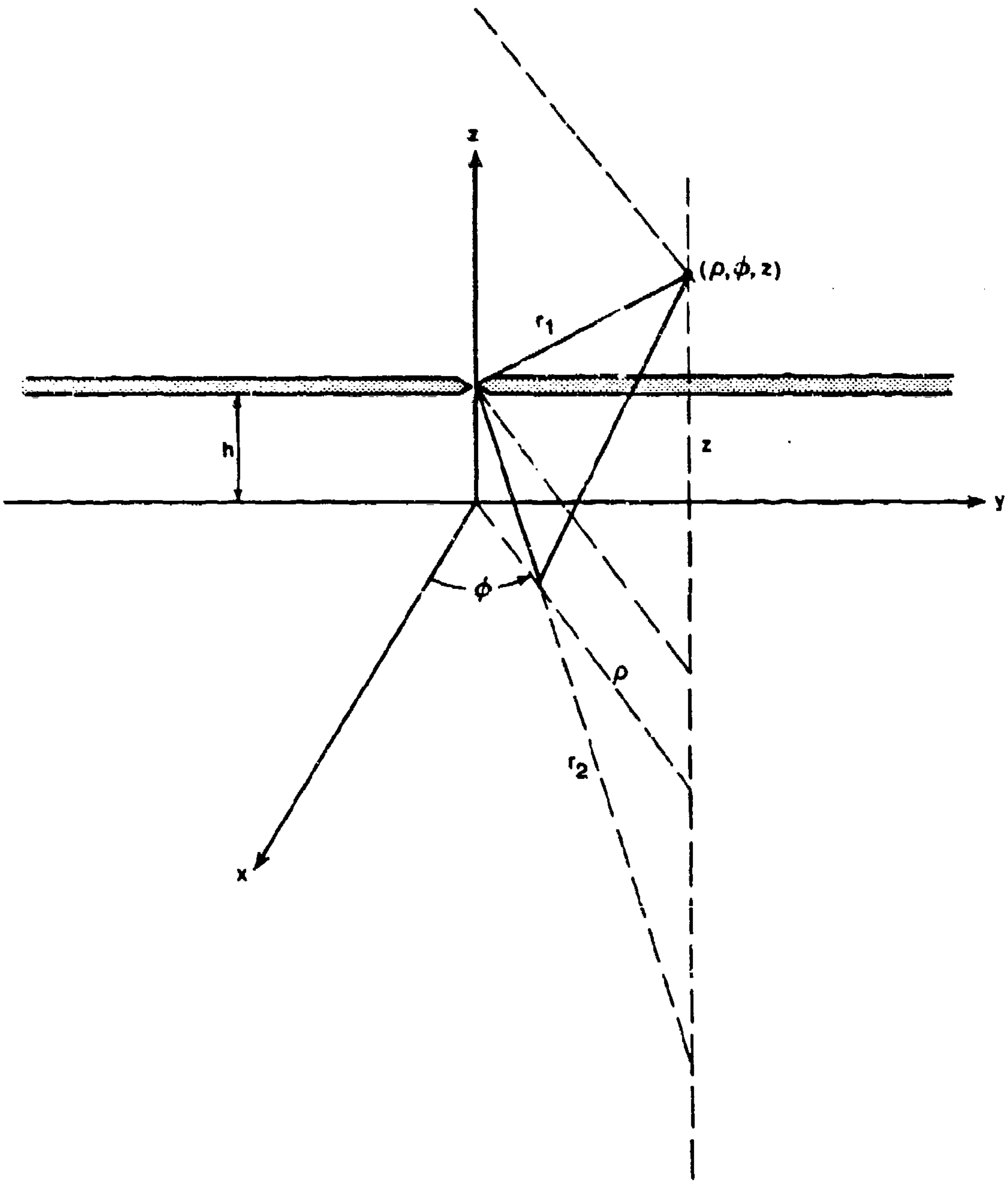


Figure 3.39 Coordinate System

where $E_D(j\omega)$ is the frequency spectrum of the direct wave. Therefore, the ground reflection decreases the low frequency content of the total field and introduces nulls or zeros at $\omega = 0$, $2\pi/T$, $4\pi/T$, ... or $f = 0$, $1/T$, $2/T$, etc. In the real case, there will be imperfect reflection at the earth's surface; however, this imperfect reflection will result in minima in the spectrum rather than zeros, but will not shift the frequency of these minima.

In support of the TACAMO EMP test program, a report of which has been published,[1] the principal component of the E-field was mapped at approximately half of the field points illustrated in Figure 3.40. This field mapping was performed using a helicopter supported E-field sensor developed by the Denver Research Institute. Figure 3.41 shows two time traces obtained at different test locations. The effect of the ground reflection and the change in the time delay can be seen in the photos. Fourier transforms of these two photos are presented in Figure 3.42. These figures illustrate how the change in the time delay shifts the location of the minima in the frequency domain. Data from this mapping operation will be found in NOLTR 73-214, Airborne Mapping of the Horizontal Empress (D.C. Koury et al, Naval Ordnance Laboratory, Silver Spring, Md., November 1973. The TACAMO aircraft over EMPRESS is shown in Figure 3.43.

Since the total field is a function of both the distance from the facility and the height above earth, the performance of the horizontal mode is generally specified in terms of the direct wave. Based on the results of the airborne field mapping and the low altitude (up to 16 meters) field mapping at the points illustrated in Figure 3.44, the risetime of the radiated pulse is approximately 4 ns and the peak field strength versus distance for 1.75 MV operation is shown in Figure 3.45. From Figure 3.45, it follows that for 2.5 MV operation, the peak field strength at 50 meters is 10.9 kV/m.

Vertical Mode

As discussed previously, the vertical mode of EMPRESS basically consists of a 100-foot high, 30-degree half-angle conical antenna,

[1] Naval Ordnance Laboratory. *EMP Test and Evaluation Report of a TACAMO IVB Aircraft* (U), by David C. Koury et al. Silver Spring, Md., NOL, December 1973. 605 pp. (NOLTR 73-227, Appendix I, publication SECRET RESTRICTED DATA, appendix unclassified.)

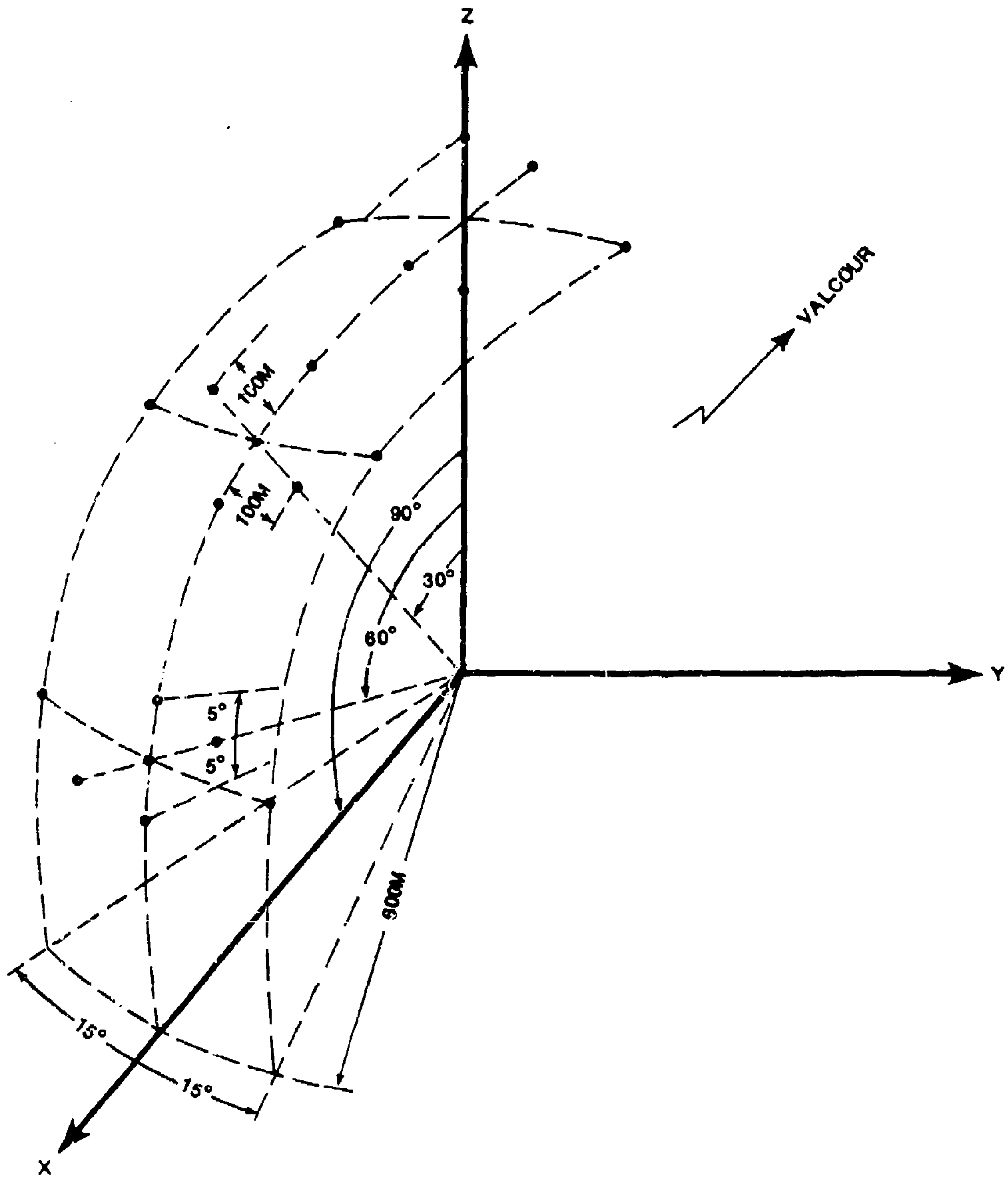
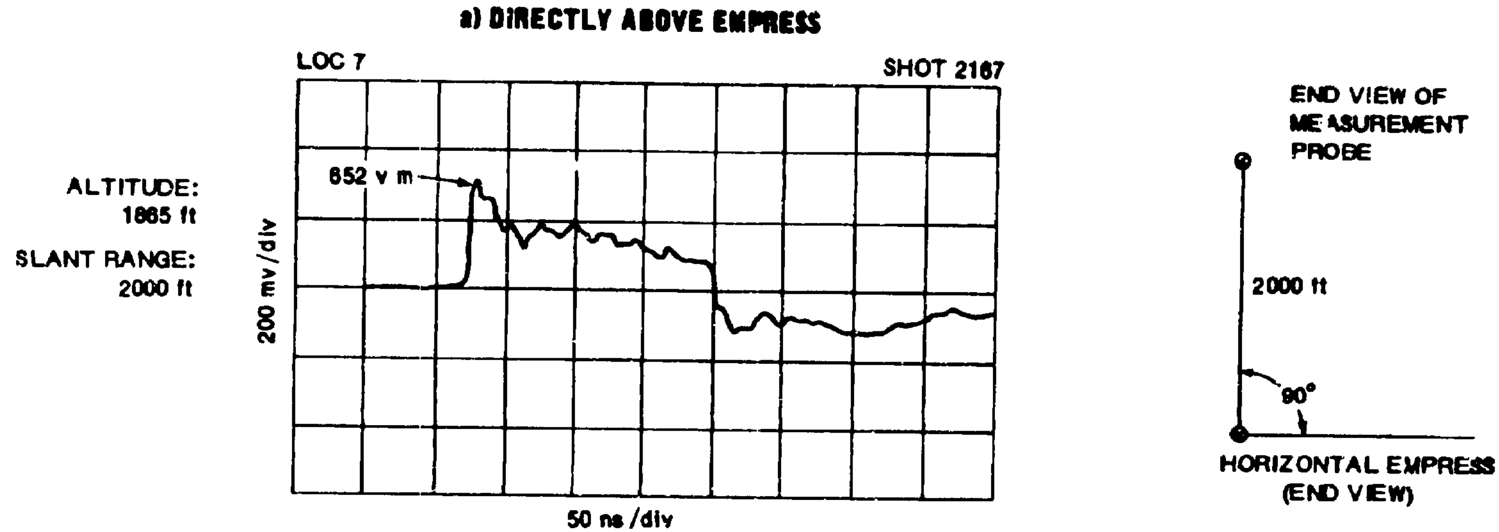
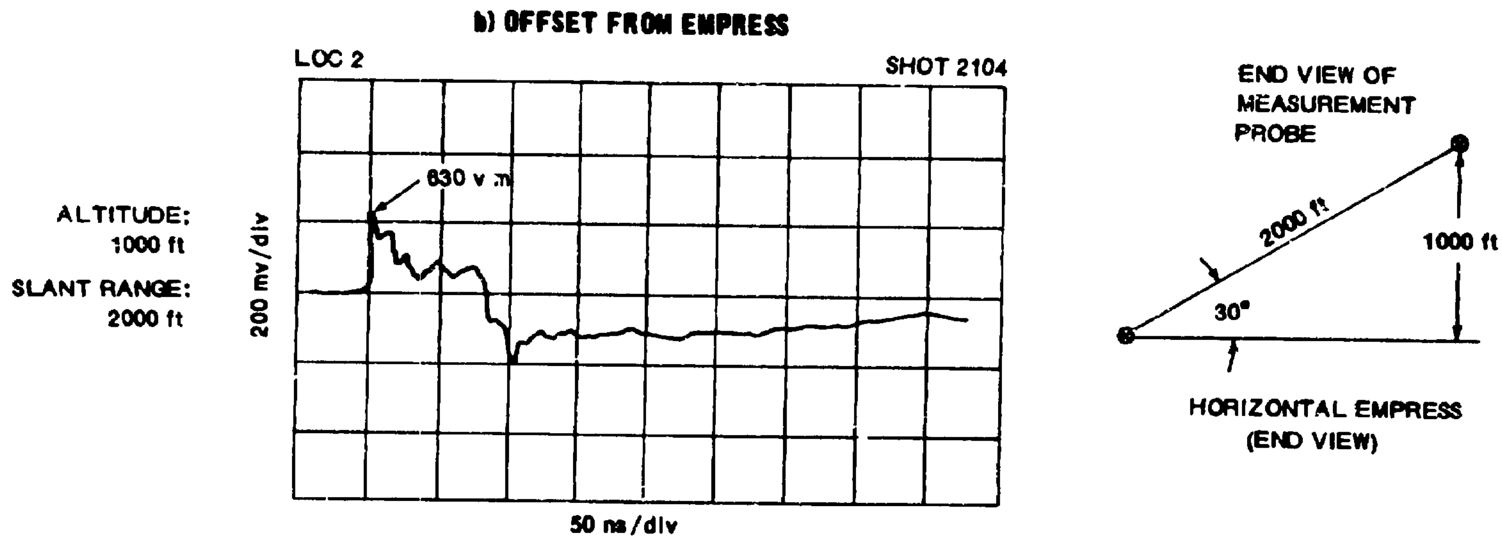


Figure 3.40 Field Mapping Points

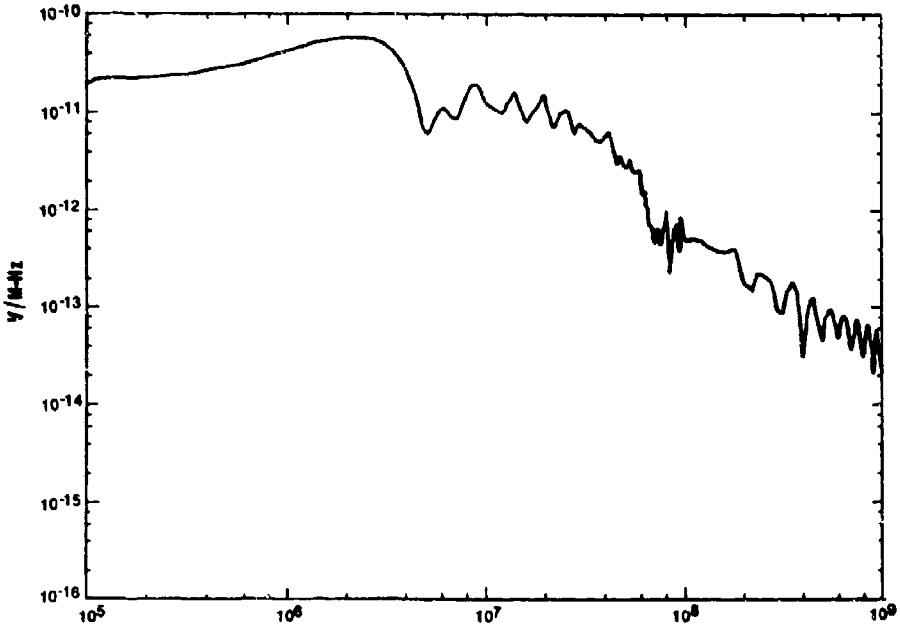


a) Directly Above EMPRESS

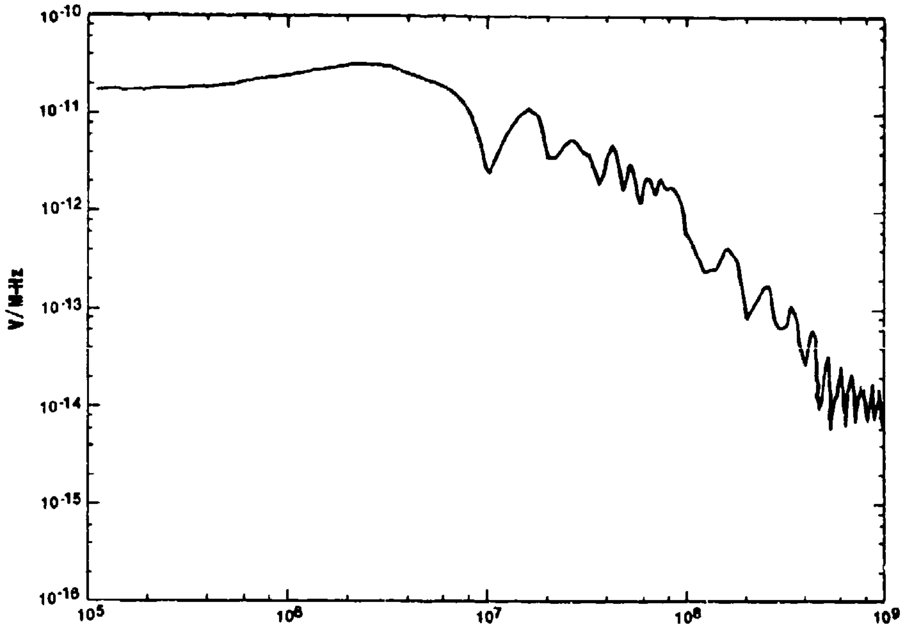


b) Offset from EMPRESS

Figure 3.41 Airborne Direct E-field Measurements of Horizontal EMPRESS Fields



A. Point 7, Shot 2167



B. Point 2, Shot 2104

Figure 3.42 Fourier Transforms

Figure 3.43 TACAMO Aircraft over EMPRESS

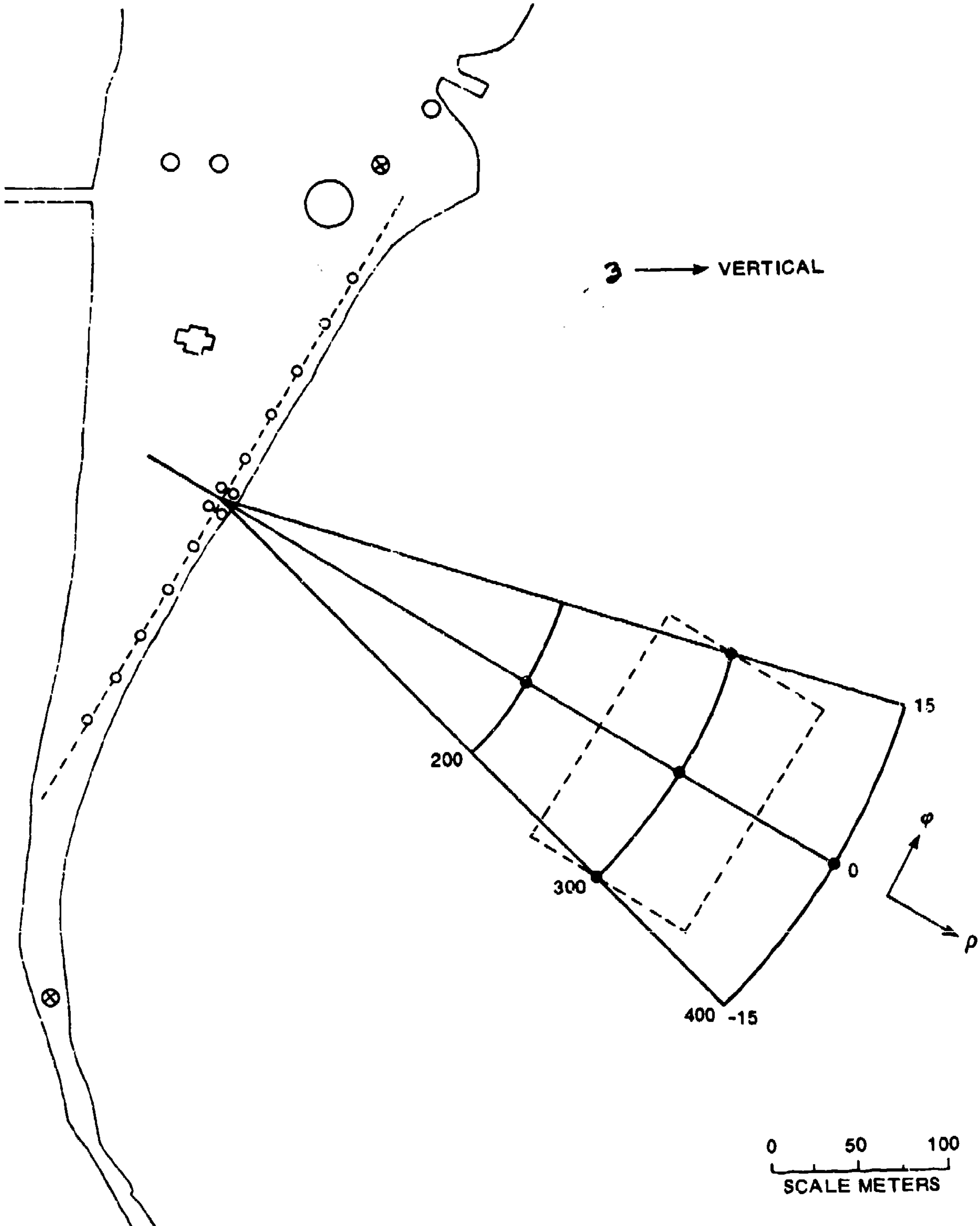


Figure 3.44 Horizontal Mode Coordinate System

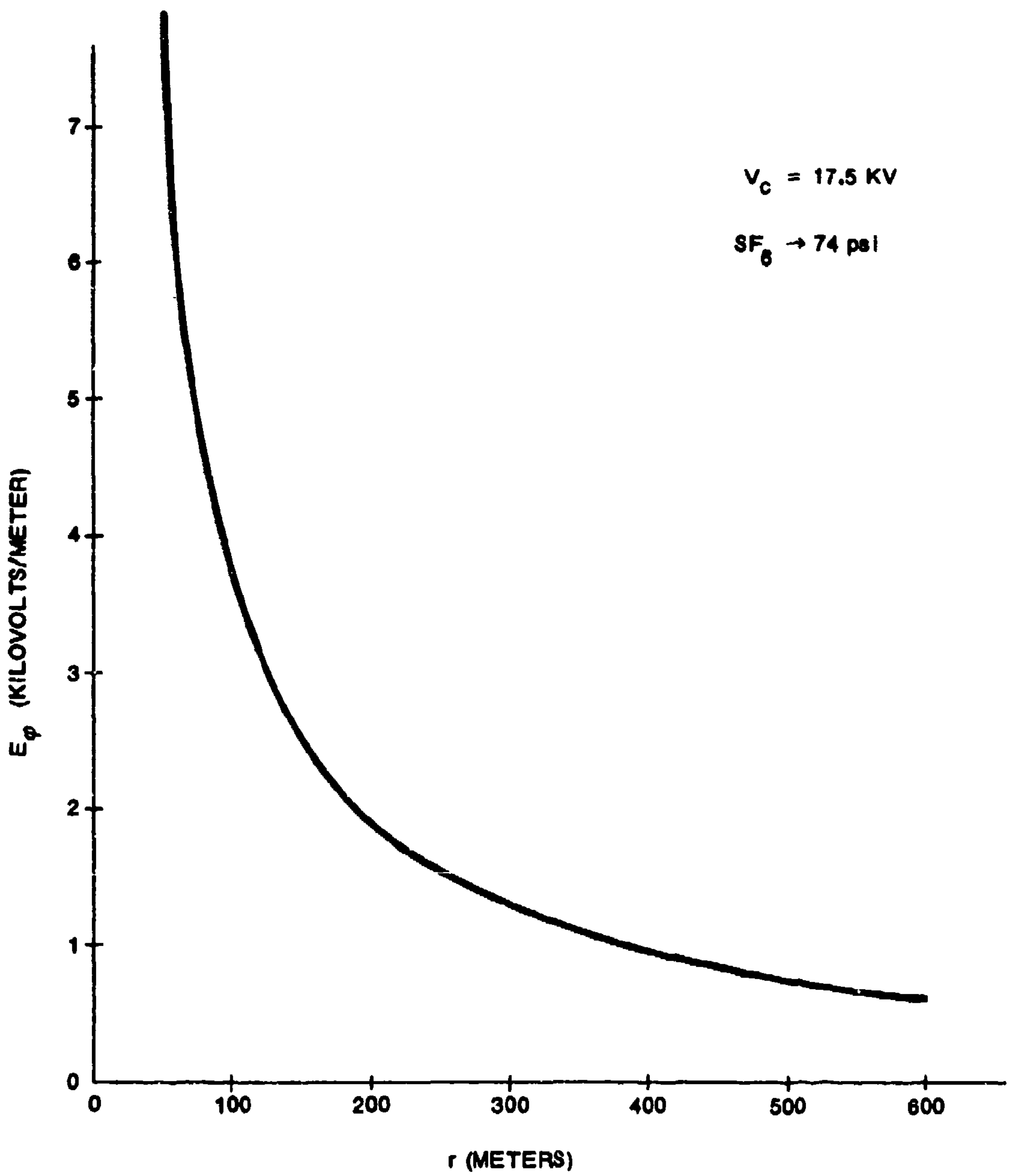


Figure 3.45 Peak Field Strength Versus Distance for Vertical Mode at Normal Operating Voltage

top loaded by the 1300-foot long horizontal line. As a guide to the performance of the vertical mode for the normal operating level (i.e. 1.75 MV), a graph of the measured peak field strength versus distance is presented in Figure 3.46. From this figure, it follows that for 2.5 MV, the peak field strength at 50 meters is approximately 24 kV/m.

As stated previously, the risetime of the radiated field is approximately 8 ns. However, due to the finite conductivity of the earth, the high frequency components are attenuated as the pulse propagates away from the simulator. Therefore, the risetime of the radiated pulse is a function of distance. Figure 3.47 is a plot of the measured risetime versus distance for the vertical mode.

3.3.5.3 Administrative Data

The EMPRESS facility is operated by the Naval Ordnance Laboratory. Information about test schedules and costs can be obtained from:

Mr. W. C. Emberson (Code 431)
Naval Ordnance Laboratory
White Oak
Silver Spring, Md. 20910

3.3.5.4 Reference Information

More detailed information concerning the facility can be obtained from the Naval Ordnance Laboratory.

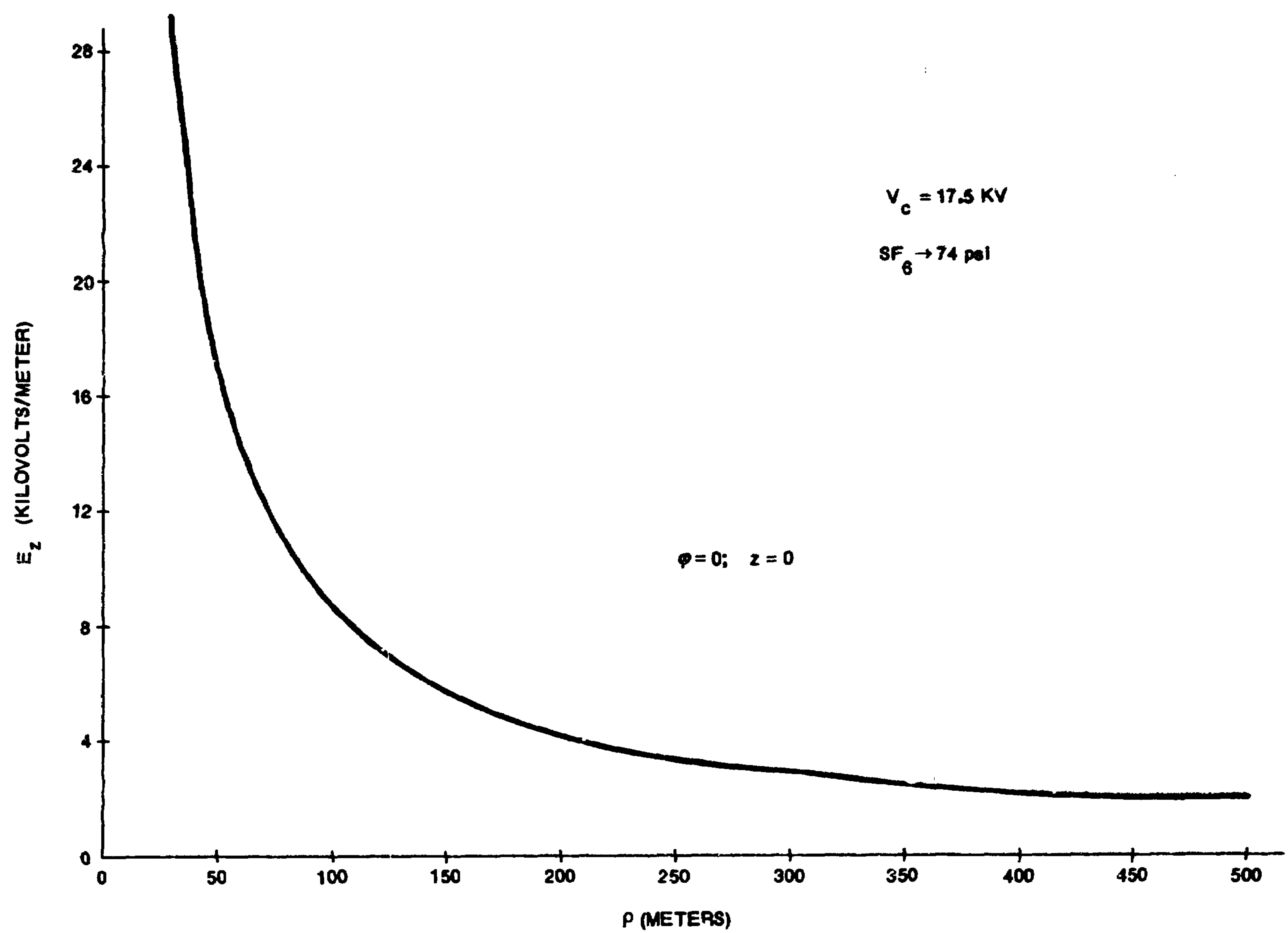


Figure 3. 46 Peak Field Strength Versus Distance for Vertical Mode at Normal Operating Voltage

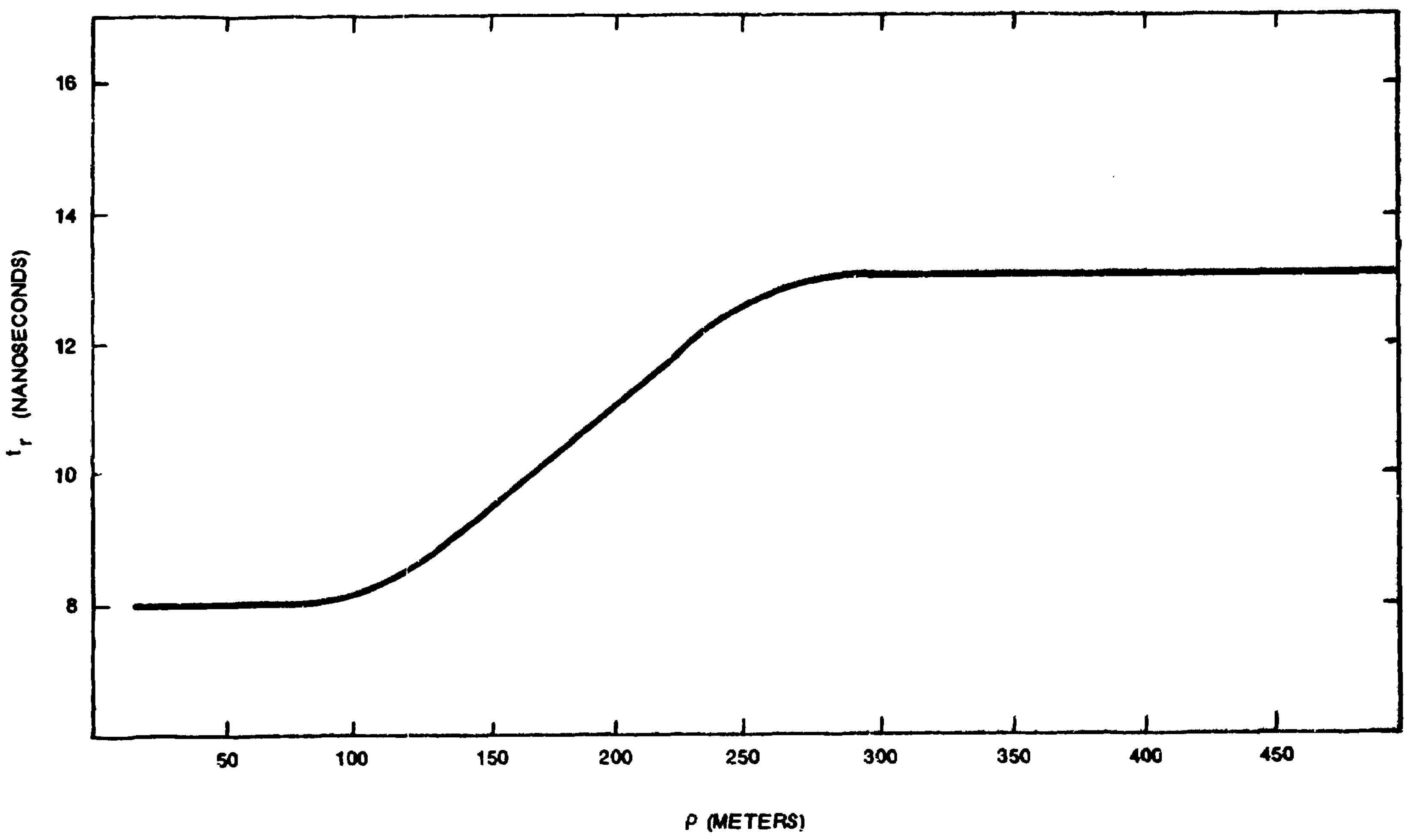


Figure 3. 47 Risetime Versus Distance for Vertical Mode

3.3.6 TORUS

The TORUS (Transient Omnidirectional Radiating Unidistant and Static) is a transportable ground-based simulator designed by the Air Force Weapons Laboratory and is being constructed for the USAF Space and Missile Systems Office (SAMSO) for use in testing Minuteman sites. Fielding of the simulator is scheduled for early 1974.

3.3.6.1 System Description

The TORUS uses a half-toroid shaped antenna which was initially designed to be supported by a helium filled balloon. Reliability problems necessitated a change in the mechanical support design. The present configuration uses guyed fiberglass towers to support the half-toroid antenna and the pulser. Concrete pads are required for the support towers. Command and control systems and other instrumentation necessary for the operation of TORUS are installed in a large trailer.

Figure 3.48 is a simplified drawing of the TORUS simulator as it might appear in testing an airplane. The simulator consists of a 5-MV pulse generator and the half-toroid antenna. Ancilliary equipment include the command and control van, portable generator, gas handling equipment and hydraulic equipment for pulser operation and various other support equipment.

A repetitive pulse generator is available for use with TORUS as well as the main high energy pulser.

Antenna

The TORUS antenna is supported by fiberglass towers and consists of a hoop supported wire cage that is anchored to the ground at

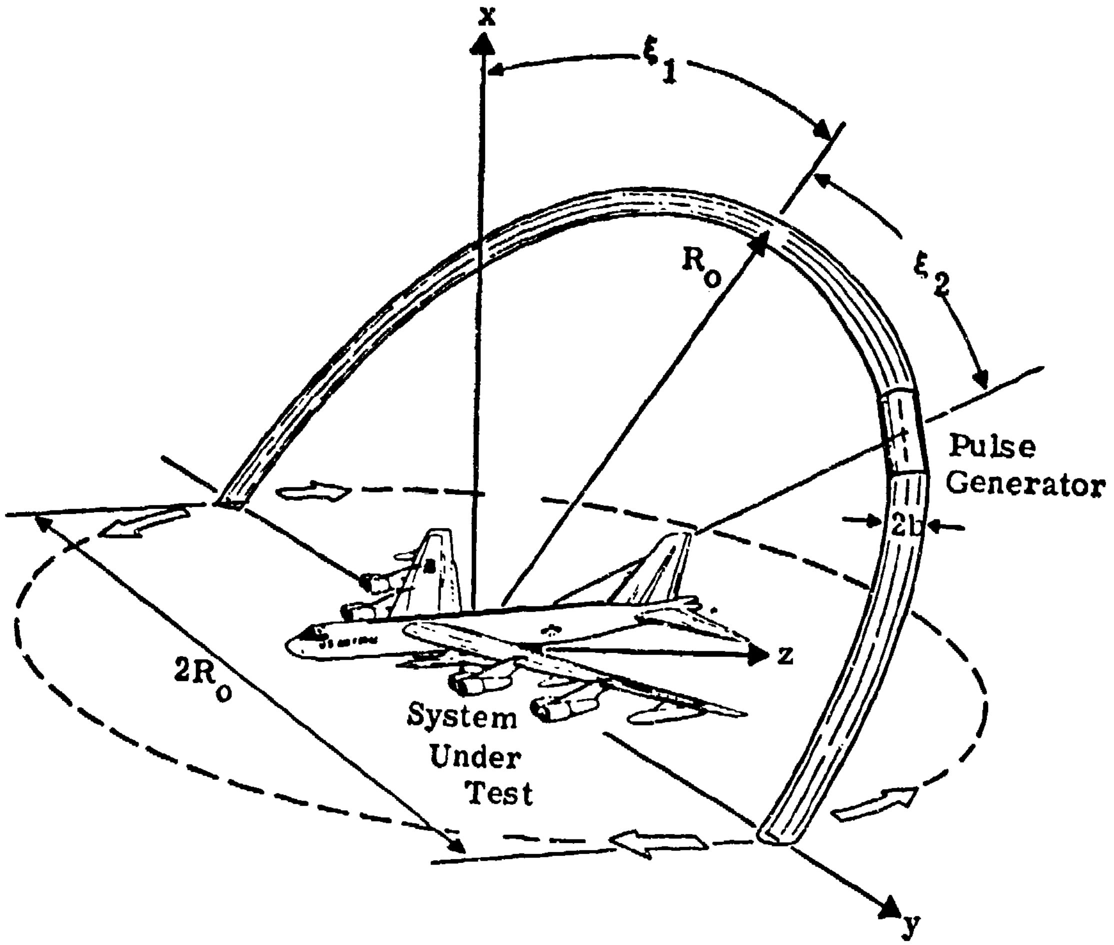


Figure 3.48 Sketch of a TORUS Antenna System

the ends to form a half-toroid. The antenna is driven by the pulser through a biconical structure on the pulser.

High frequency components are radiated by the bicone structure and intermediate frequency components are radiated by the toroid loop. A late time magnetic dipole is formed because of current flow through the ground return path.

The angle of the plane of the toroidal arch with respect to the vertical is adjustable. The position of the pulser along the arch is also adjustable. Simulation of various nuclear burst positions is possible by means of these adjustments.

The TORUS antenna is designed to provide good simulation of both early time high-frequency components and late time low-frequency components of nuclear EMP.

Pulser

The main pulser is a single shot pulser built by Maxwell Laboratories. It consists of two 2.5 megavolt Marx generators (Figure 3.49). One of the Marx generators is grounded through one side of the antenna and the other Marx generator is grounded through the other side of the antenna. They are connected together at the center of the bic·ne

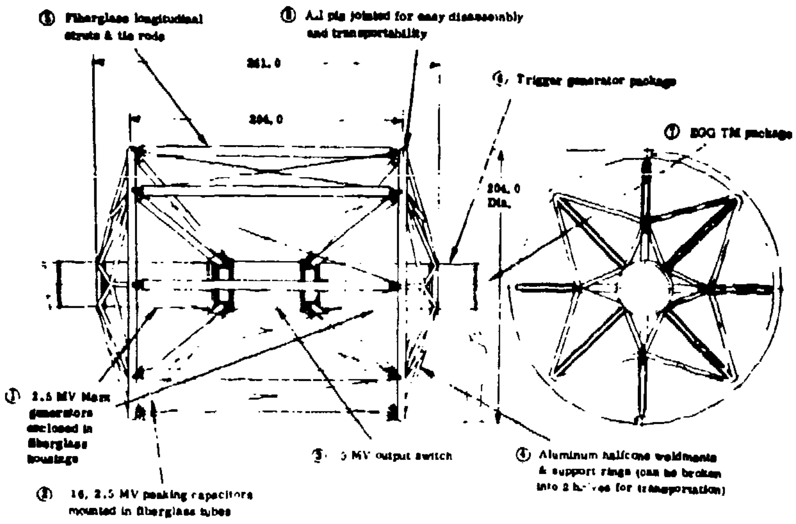


Figure 3.49 TORUS 5-MV Pulser

through a switch which is housed in a mylar bag that is pressurized with SF_6. The two Marx generators are erected simultaneously to opposite polarity and discharged through the switch. Eight peaking capacitors are built into the bicone struts on each side. Maximum energy storage for the main pulser is 25,000 joules.

Instrumentation

B-dot sensors are available to monitor the pulser output and to generate a fast trigger pulse that can be made available to the system user. Some pre-trigger sequencer functions are also available.

3.3.6.2 Electromagnetic Characteristics

The radiated field risetime is approximately 10 ns with a pulse length of 1000 to 10,000 ns. The maximum attainable field strength is to be 50 kV/m. Because of the adjustable toroid angle of inclination and the adjustable pulser position, these fields may be produced with horizontal, vertical or intermediate polarizations. The TORUS is a hybrid type simulator.

3.3.6.3 Administrative Data

The TORUS will be maintained and operated by SAMSO. The SAMSO Project Officer is Major C. Allen. The system is scheduled for use in testing Minuteman sites through 1978.

3.3.6.4 Reference Information

Further detail concerning the TORUS system can be obtained from the following:

- "TORUS I R & D Contract Status Report", EG&G Report AL-589, June 1971
- "TORUS I Operation and Maintenance Manual", Maxwell Laboratories, Inc., AL-817, July 1972

3.3.7 HPD

The Horizontally-Polarized Dipole (HPD) simulator is designed for the testing of airplanes and is presently being constructed by EG&G on Kirltand AFB for the Air Force Weapons Laboratory. Completion of the simulator construction and field mapping are scheduled for July 1974.

3.3.7.1 System Description

An artist's concept of the completed HPD simulator is shown in Figure 3.50. The basic dimensions of the simulator are also shown. The simulator is designed to be large enough for testing very large airplanes such as the C-5A shown.

The facility will consist of the horizontal dipole simulator, a parking pad and access taxiway for the test object, various instrumentation and data recording devices, and support facilities.

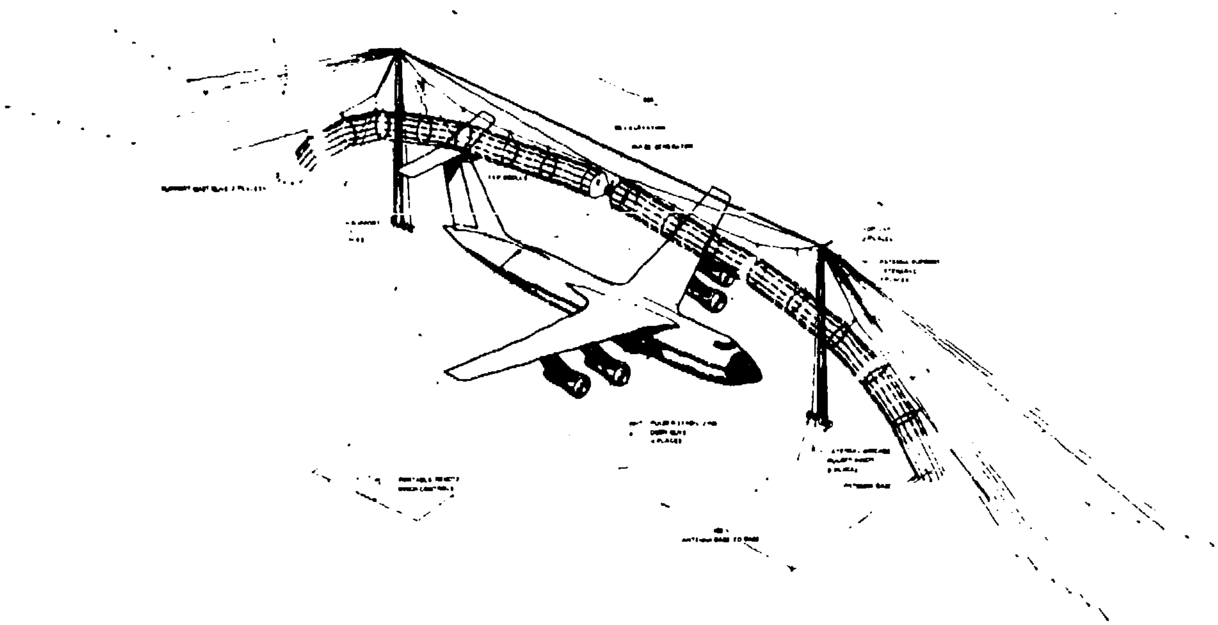


Figure 3.50 HPD Concept

The HPD simulator will consist of a pulser centered in a long wire cage antenna which is supported above the ground on a rope catenary from two 120-foot high laminated wood masts. There will be no metal ground plane. Instrumentation will be located in a trailer with support facilities located to the side so as to minimize reflections. The antenna forms a half ellipse with a major diameter of 492 feet and a minor diameter of 196.8 feet. In its test mode, this design places the pulser 98.4 feet above the ground. The cylindrical antenna has a minor diameter of 17 feet. The antenna is formed by 12 wires supported every 34 feet by metal hoops. Each module contains four resistor packages equally spaced in each of the 12 wires. The resistor packages are series combinations of 10 wirewound resistors. The resistance of each resistor string will be about 120 Ω. Approximately 800 of these resistor strings will be included in the antenna. The total resistance in the half ellipse will be about 630 Ω.

This configuration is electrically similar to the TORUS system being developed by SAMSO. One important feature of the HPD design is that the test airplane can be placed directly below the pulser/antenna, as well as off to the side for the conventional "broadside" testing. The capability of rotating the airplane under the pulser will be very important in understanding the interaction of the airplane with the electromagnetic fields. The suspension system is capable of raising or lowering the antenna and pulser with electric winches in less than 45 minutes.

Two different high-voltage pulsers can be used in the HPD. Pulsar Associates, Inc. is building a Pulsepak 9000 pulser which will drive the antenna with a 5-MV pulse. As shown in Figure 3.51, the pulser consists of two 2.5 MV Marx generators symetrically driving a gas insulated switch.

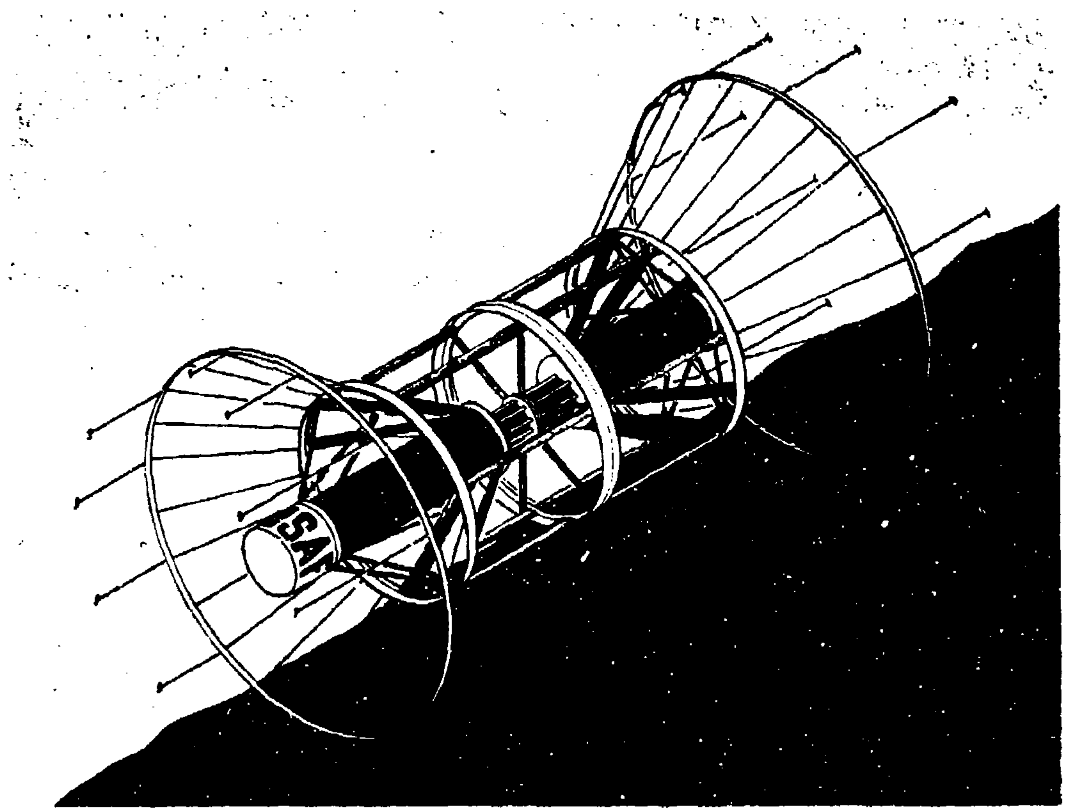


Figure 3.51 Sketch of PULSPAK 9000 5-MV Pulser

The entire pulser will be enclosed in a bag filled with SF_6 for electrical insulation.

The 5-MV switch is connected to the antenna through dielectric peaking capacitors arranged to form a biconic radiator. The bicone impedance is approximately 120 Ω.

The second pulser to be used with the HPD is the 1.8 MV RES-I pulser described in earlier sections.

3.3.7.2 Electromagnetic Characteristics

The HPD is a hybrid type simulator providing predominately horizontally-polarized fields. Measured electromagnetic fields in the simulator will not be available until field mapping tests have been completed. Some theoretical predictions of the radiated fields, however, have been made.

For the early time regime, the simulator can be approximated as a point source radiating a spherical wave. The analysis consisted essentially of dividing the electric field vector into convenient components and then superimposing the incident and ground reflected waves at various points in the simulator. The reflected waves, because of their longer path length, are delayed in time with respect to incident fields; also the reflected signal is smaller since total reflection occurs only at grazing incidence. The calculations assumed a pulser charge voltage of 1.8 MV (RES I pulser) and a pulser risetime of 4.0 ns. Reflections at the pulser bicone - dipole interface were not taken into account.

Late time, or quasi-static, regime predictions were obtained from line integrals around the simulator structure multiplied by time-dependent currents on the antenna. The currents were obtained by modeling the simulator as an RC circuit with a capacitive generator discharging into the resistance.

Figure 3.52 shows the points for which field predictions were made. Figures 3.53 through 3.56 show the calculated fields for Positions 1 and 2. Because of the apporximations used, the field strengths shown

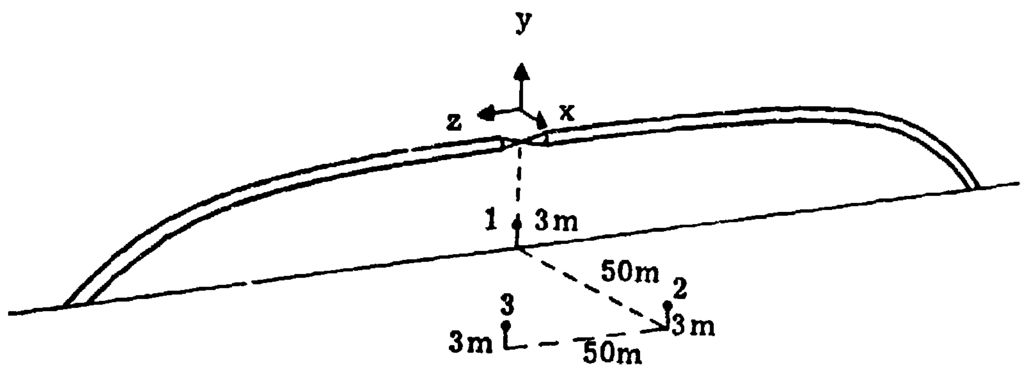


Figure 3.52 Observer Positions used for HPD Predictions

serve only as lower bounds for early time predictions and upper bounds for late time predictions. The maximum electric field at Position 1 was about 25 kV/m. At Position 2 the z component of the electric field is reduced to about 12 kV/m.

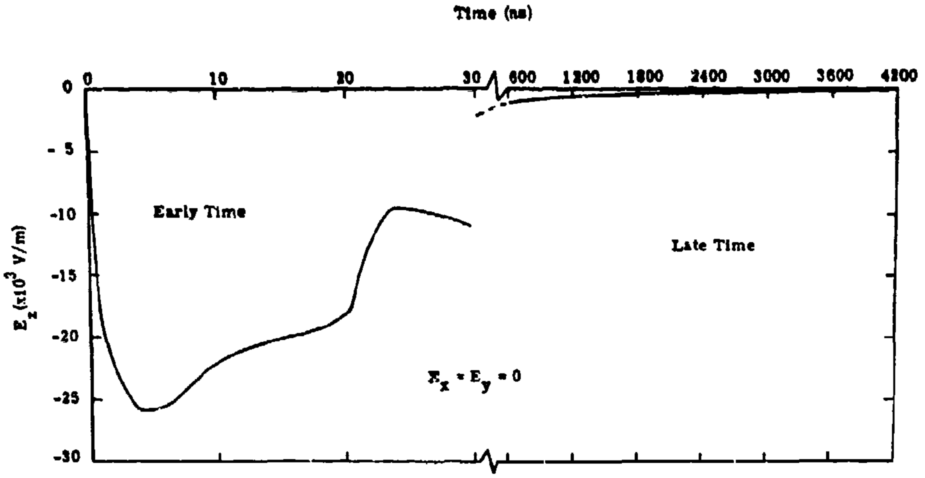


Figure 3.53 E_z Waveform at Position 1

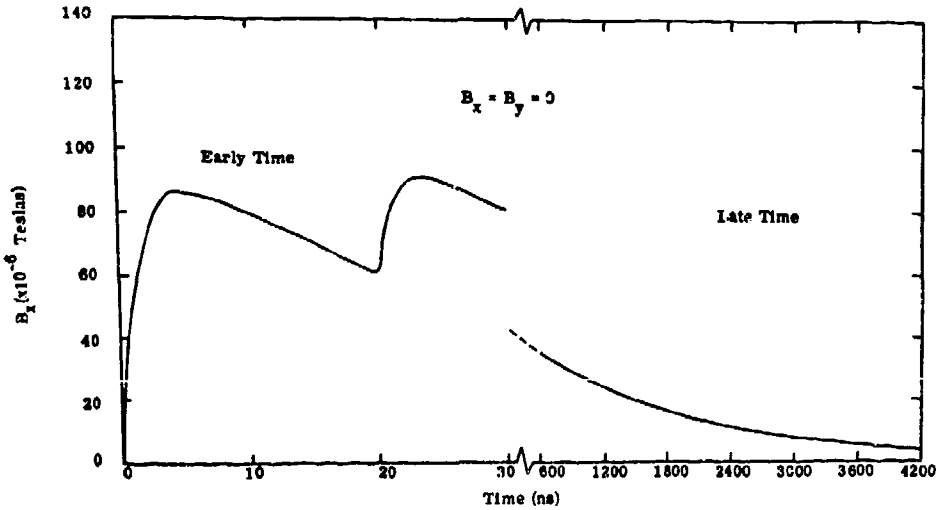


Figure 3.54 B_x Waveform at Position 1

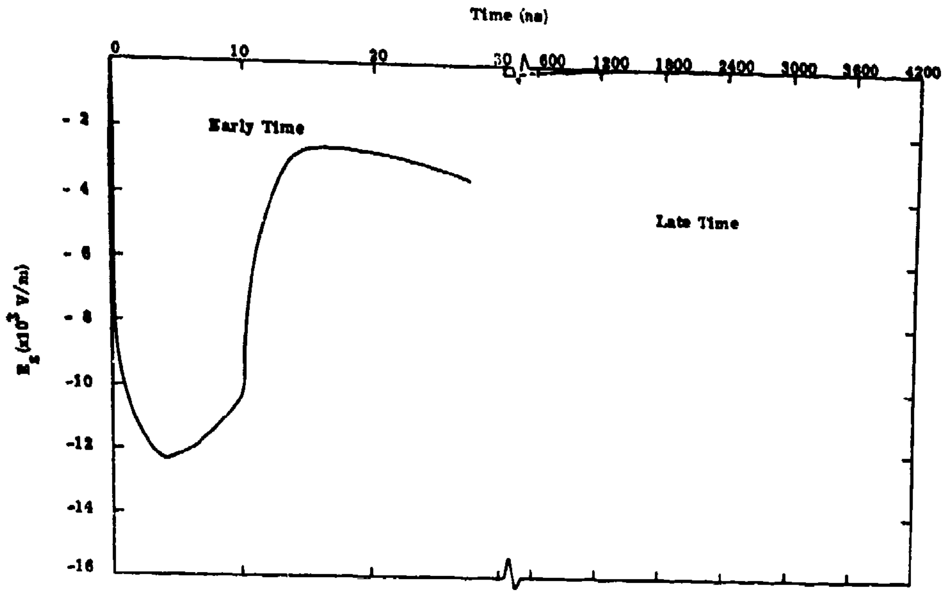


Figure 3.55 E_z Waveform at Position 2

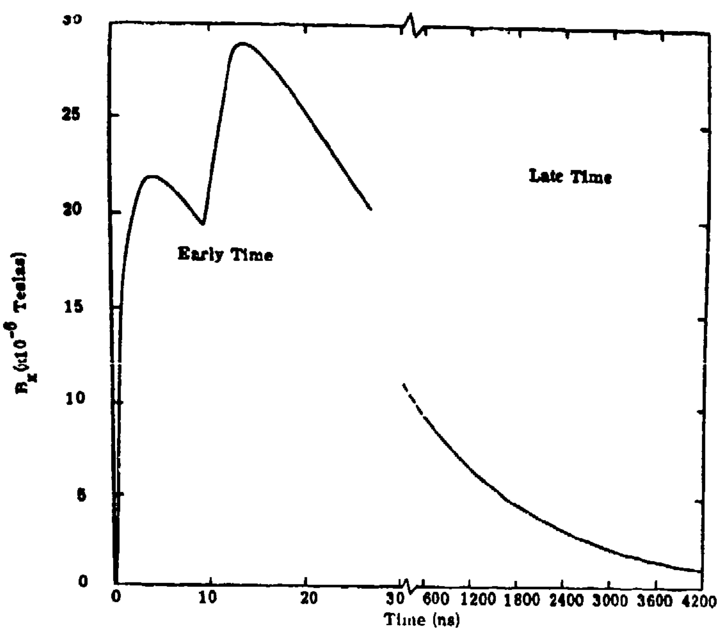


Figure 3.56 B_x Waveform at Position 2

3.3.7.3 Administrative Data

The HPD will be maintained and operated by the Air Force Weapons Laboratory. The AFWL Project Officer is:

Captain Dean Logemann
AFWL/ELS
Kirtland AFB, New Mexico 87114
Telephone: 505-264-1816

The FB-111 airplane will be tested in the HPD in late 1974. Future tests will include the Advanced Airborne Command Post (AABNCP), the Airborne Warning and Control System (AWACS), and the B-1 airplanes.

Rental costs for the facility are estimated to be about $10,000 per month based on a standard 5-day week and single-shift operation. This estimate is based on past test programs in the VPD facility. The user would pay all costs actually incurred during the tests. For further information, contact the AFWL Project Officer.

3.3.7.4 Reference Information

More detailed information concerning the HPD design can be obtained from the following:

- "Final Report, Horizontal Dipole EMP Simulator Design Study", EG&G Report AL-590, June 1971.
- "EMP Simulation Facilities for Aeronautical Systems EMP Program", June 1972 (available from AFWL).

3.3.8 TEMPS

The TEMPS I (Transportable Electromagnetic Pulse Simulator), sponsored by the Defense Nuclear Agency, was designed and built by Physics International Company for the Harry Diamond Laboratories. The TEMPS simulates the electromagnetic environment produced by exoatmospheric nuclear bursts. These simulation experiments are conducted on ground based Department of Defense systems. Included among them are permanent installations as well as mobile military systems. Specifications dictated a complete, self-contained simulator that could be completely transported to remote sites, rapidly erected, checked out, and reliably operated to conduct EMP tests.

A second simulator, TEMPS II, is being permanently installed at Harry Diamond Laboratories for Army tests. This simulator, identical to TEMPS I (but not transportable), will be operational in February of 1974. It is possible that this simulator will be available to a secondary user on a non-interference basis.

3.3.8.1 System Description

The system is a synchronized bilateral Marx-generator/peaking-capacitor pulser that drives the terminals of a long (300 meters) dipole antenna, positioned horizontally over earth ground at elevations of up to 20 meters. The characteristics of the electromagnetic wave launched from the system are determined by the pulser in conjunction with the antenna and its position relative to ground.

A biconical transmission line, with a characteristic impedance of 120 ohms at the center of the antenna, guides the electromagnetic wave from the small dimensions of the pulser, contained within the bicones, to the 9.2 meter diameter cylindrical wire-cage dipole antenna. Each end of the antenna is terminated to ground with a resistance that approximately matches the characteristic impedance of each half of the antenna, which is viewed as an equivalent rod-to-plane transmission line to ground.

Essentially, TEMPS has three individual subsystems: the pulse generator, the antenna, and the support structure.

Pulser

A simplified circuit of the TEMPS generator is shown in Figure 3.57. C_g is the erected series capacity of each 35-stage Marx generator; L_s is the stray inductance of each half generator; and R_s is the sum of stray and lumped series resistance, of which 10.5 ohms are lumped and distributed throughout each Marx (0.3 ohm per stage) to limit current and reduce Marx capacitor voltage reversal in the event of a fault. R_{shunt} is the equivalent shunt resistance associated with Marx charging and triggering resistors; and C_p is the value of the generator peaking capacitors

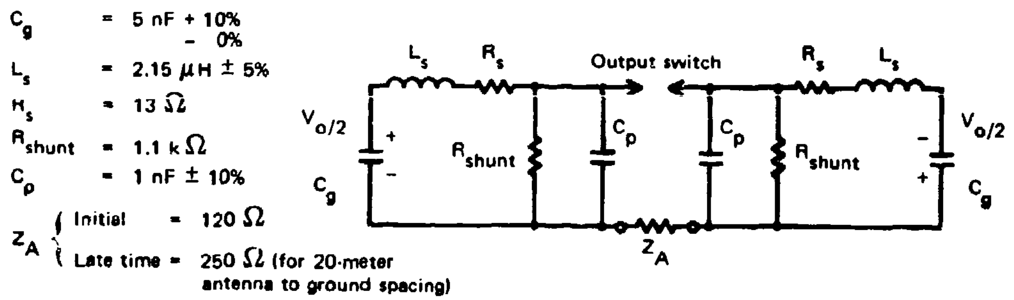


Figure 3.57 TEMPS Pulser Circuit Diagram

required to produce the early time, fast rising load current that the Marxes, because of their stray series inductance, cannot supply.

Eight peaking capacitor modules are used in each half generator and are distributed to form a continuation of the conducting biconical transmission line surfaces to which they are attached.

The sequence of electrical operations culminating in the launch of an EM pulse begins with dc charging of the Marx generators to a maximum of 90 kV in about 40 seconds, and when synchronously triggered (within a few nanoseconds of one another), they pulse charge their respective peaking capacitors on a $(1 - \cos \omega t)$ waveform in about 55 nanoseconds.

Typical peaking capacitor pulse charge and output voltage waveforms ($V_o \cong 4.1$ MV) are shown in Figure 3.58. These waveforms

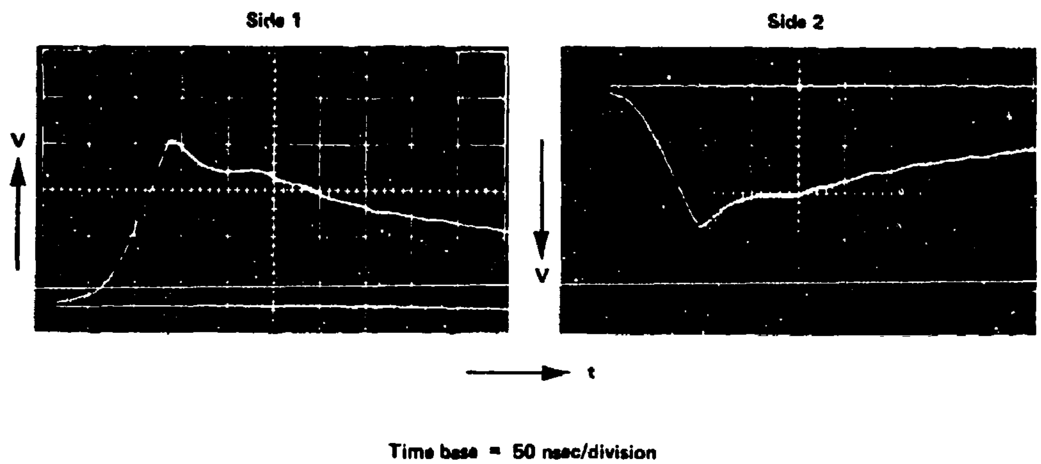


Figure 3.58 Typical Pulser Waveforms

are derived from resistive voltage divider monitors installed across the peaking capacitors on each side of the system. The monitor outputs are fed to oscilloscopes contained within screen boxes located on-board the pulser, one on each side of the system. Oscilloscope power is derived from battery/inverter sets also contained within the screen boxes.

The pulser output switch, a near uniform field, pressurized-gas spark gap with remotely adjustable gap spacing, is adjusted to self-break at the appropriate time ($t_s \simeq \pi/2\omega$) during peaking capacitor pulser charge (peak voltage in the above photographs), thus discharging the pulser into the antenna.

Synchronization is necessary in TEMPS so that overvoltage of a half generator is avoided and that an output pulse shape is reproduced from shot to shot. This requirement was met by employing a low timing jitter trigger system. The timing jitter is less than 2 nanoseconds (rms).

Instrumentation

Data from system response instrumentation ($\dot{D}$ and $\dot{B}$ sensors) is transmitted from measurement points to the instrumentation van, which houses recording oscilloscopes and cameras, via an EG&G microwave dielectric waveguide link. Four separate channels of data can be handled simultaneously. Each channel consists of three oscilloscopes/cameras allowing for three separate sweep speeds. There are two spare oscilloscopes and cameras. The length of any individual data link channel can exceed 125 feet.

The calibration instrumentation is sufficient to maintain the accuracy of the system response instrumentation. The dielectric constant and conductivity of the ground are measured by using a system which employs a two wire line above the ground to determine the ground parameters in situ.

Antenna

The antenna, Figure 3.59, is a cylindrical system of wires extending from each end of the pulser assembly, with associated forming hoops and assemblies, tensioning elements, and end ground terminations which launch and guide the EM wave.

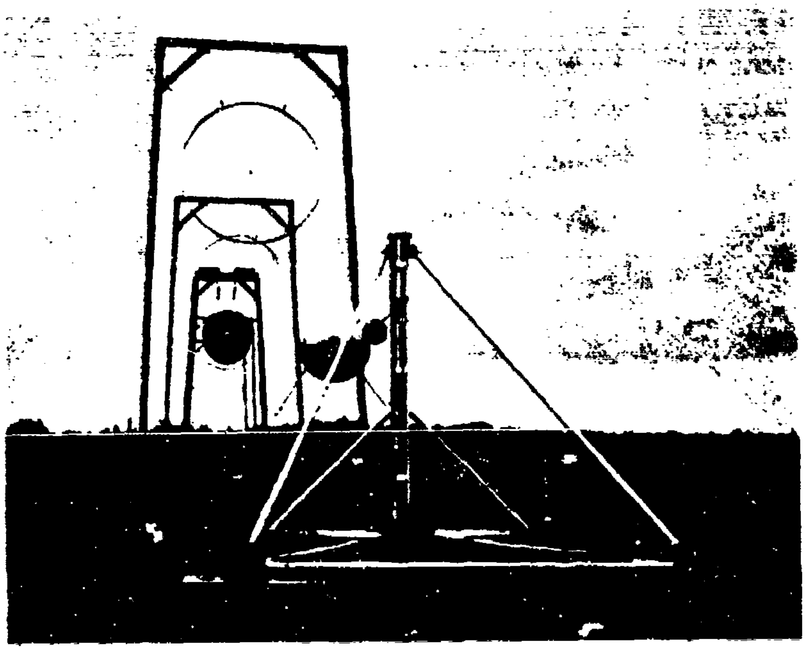


Figure 3.59 TEMPS Antenna

The assembly forms a 120-ohm biconical radiator which launches the high-frequency early portion of the pulse with minimum distortion. The bicones are solid to a diameter of 23 feet and are tapered to a cylinder 30 feet in diameter with a conic-section wire cage.

The 30 foot diameter cylindrical wire cage dipole radiates low frequency energy. The length of this dipole can be varied in 100 meter increments to a maximum of 300 meters. Each end of the dipole is resistively terminated to earth through a conical-section taper designed to maintain characteristic impedance of the dipole to the terminating resistors.

A modular, easily erectable, fiberglass structure supports the pulser, bicones and antenna. This structure requires minimal preparation for erection and is adaptable to particular antenna configurations desired. The support structure allows the antenna height to be varied up to 20 meters and permits operation in wind velocities up to 28 mph.

3.3.8.2 Electromagnetic Characteristics

The TEMPS is a hybrid simulator. Peak free fields of up to 52 kV per meter can be obtained at 50 meters from the pulser. This output pulse level can be remotely adjusted over a 3:1 range. The fields are predominantly horizontally polarized.

The TEMPS is designed to produce a double exponential output pulse with less than 20% undershoot. Pulse risetime is adjustable (about 8 ns at most output levels). At maximum antenna length, pulse duration to first crossover is approximately 800 ns.

The broadside coverage of the TEMPS simulator for the fast risetime peak fields is 50 meters at a distance of 50 meters from the simulator. Over this range, the peak field will vary less than 10%. The nominal TEMPS test area is illustrated in Figure 3.60. TEMPS can provide an angle of incidence of 10° to 20° depending on antenna height.

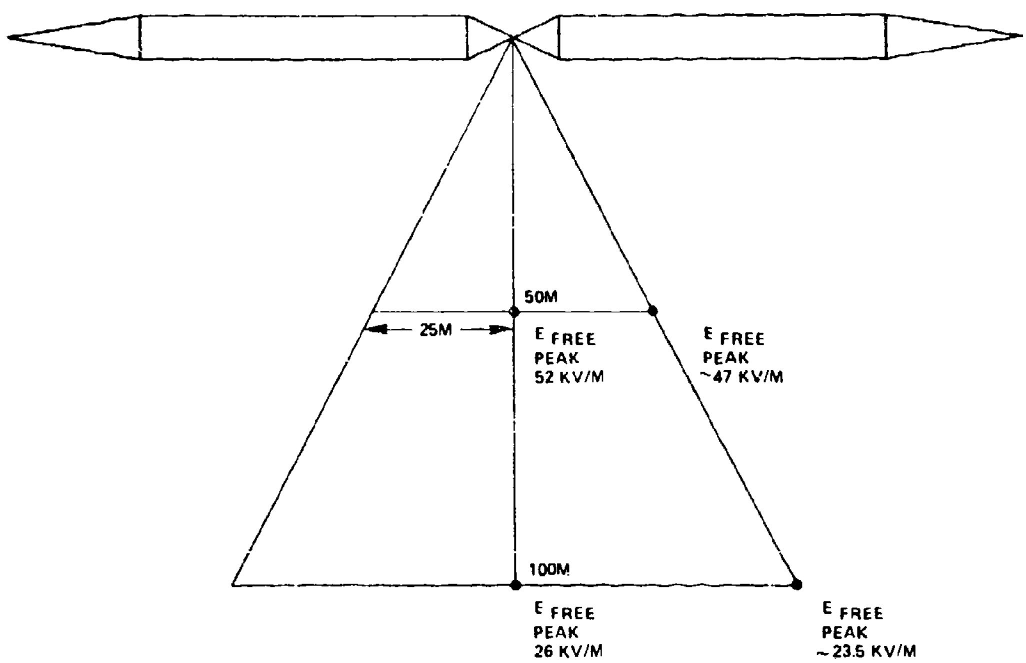


Figure 3.60 TEMPS Coverage Area

Dominant features of the early time pulse shape can be seen in the waveform of Figure 3.61. For this shot, pulse amplitude was approximately 200 amperes/meter (corrected for prepulse), and reached this value in 8 nsec (10% - 90%). The corresponding peak electric-field intensity is about 46 kV/m, referred to a radial distance of 50 meters from the antenna on the equitorial plane of the system. This waveform also shows the system prepulse, which arises as a result of stray capacity across the TEMPS output switch. This stray capacity couples a small fraction of peaking-capacitor pulse-charge current into the antenna prior to output-switch closure. The prepulse amplitude is about 8% of peak. However, for the probe position, this prepulse is a ground interacted value and true prepulse amplitude is more nearly 16% of peak field.

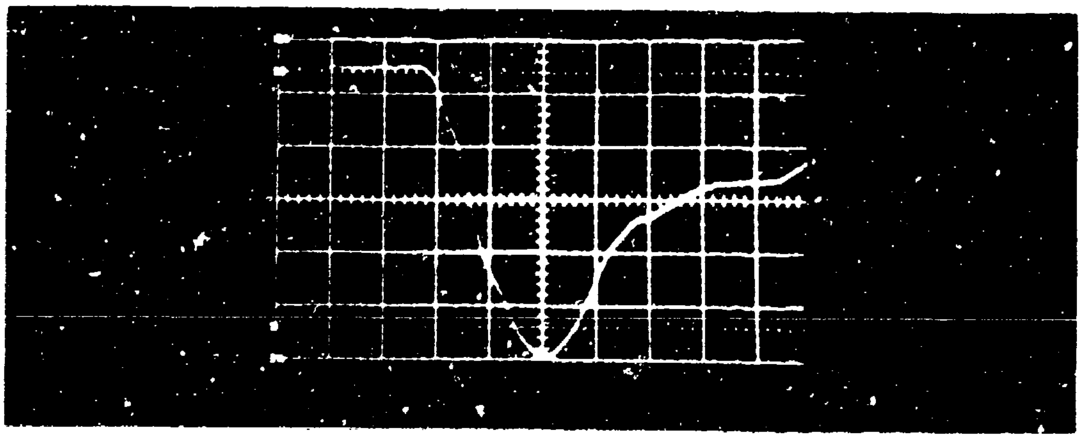


Figure 3.61 TEMPS Output Waveform

The waveform in Figure 3.62 is representative of the time variation of the tangential magnetic field for a probe position 50 meters horizontal from the antenna and close to earth ground. To a large extent, departure of the waveform from a perfectly smooth one arises from vertical components of antenna current (at the metal antenna hoops and termination), and gives rise to tangential magnetic fields disproportionately large compared with the incident free-field magnetic field. The spectral content is shown in Figure 3.63. However, the field sensor used for these measurements has no response at dc and, thus, the indicated spectral content at low frequencies is not strictly valid.

A summary of the TEMPS electromagnetic environment characteristics is given in Table 3-6.

TABLE 3-6

Summary of TEMPS Characteristics

Pulse Shape	Double exponential
Pulse Duration	800 ns
Pulse Undershoot	20% of pulse peak
Pulse Amplitude	18 kV/m to 52 kV/m
Pulse Risetime	4 ns to 12 ns
Angle of Incidence	10° to 20° at 50 m ground range
Coverage	±25 m on a line parallel to antenna axis at 50 m ground range

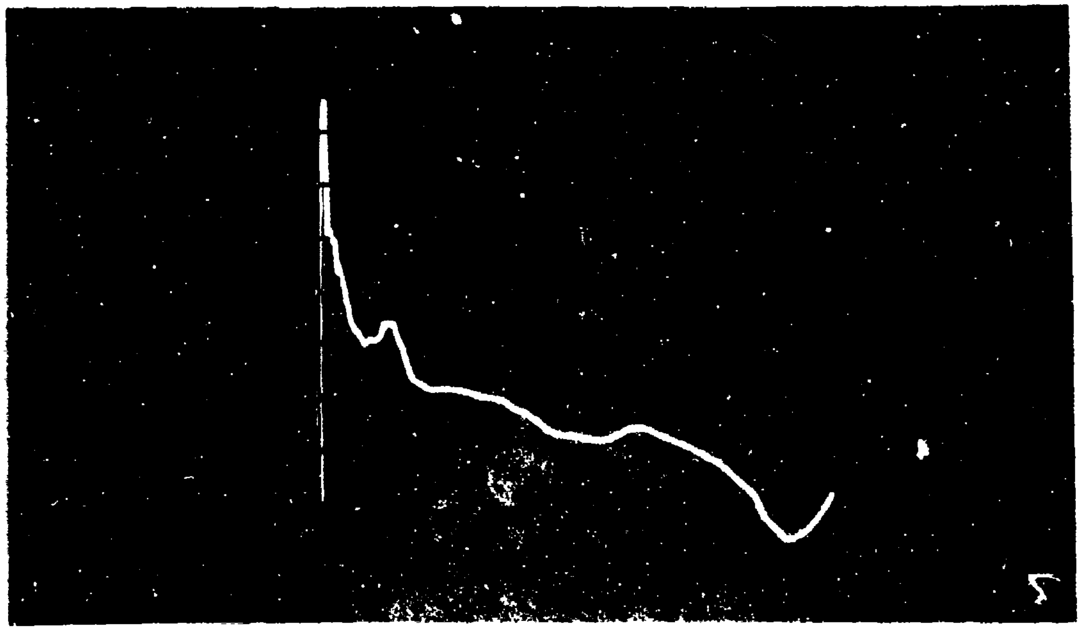


Figure 3.62 Tangential Magnetic Field at 50 Meters

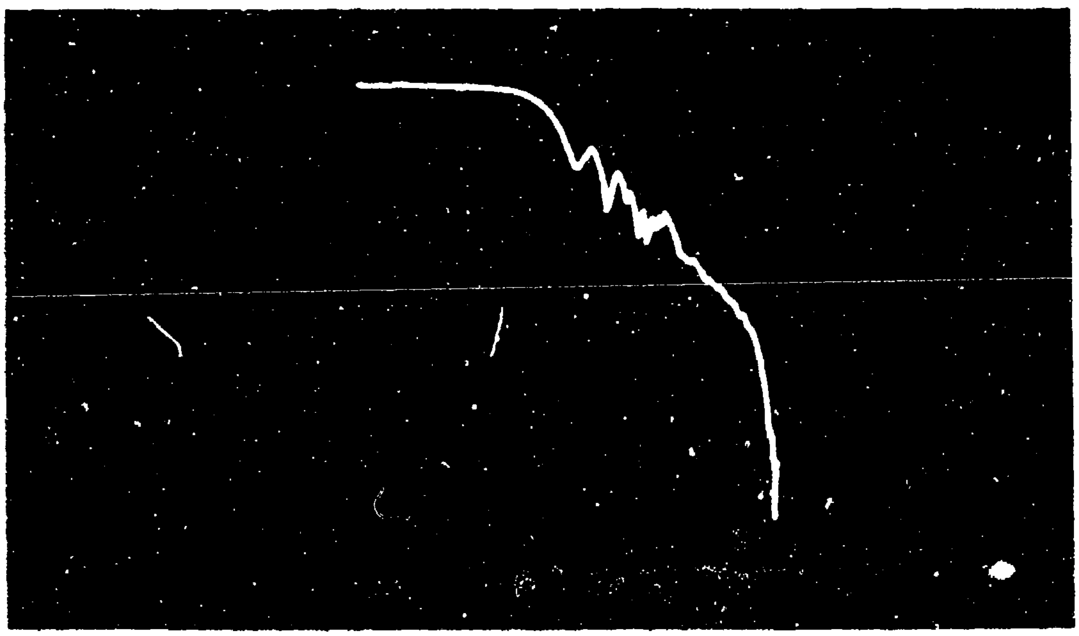


Figure 3.63 Spectral Content at TEMPS Field

3.3.8.3 Administrative Data

The TEMPS systems are maintained and operated for the Defense Nuclear Agency by the Harry Diamond Laboratories. The HDL Project Officer is:

Mr. William Petty
Telephone: 703-664-3691

The DNA Project Officer is:

Major Walt Youngblade
Telephone: 703-325-7067

At present, TEMPS I is committed to PREMPT testing (DCA/DNA) until late 1975. TEMPS II will be used for Army tests at HDL but might be available to a secondary user on a non-interference basis.

Rental costs for TEMPS amount to roughly 1.0 to 1.5 million dollars per year. The fee includes the costs of all instrumentation and the Harry Diamond Laboratory's 18-20 man operating crew. Because of the highly variable expenses of site preparation and dismantling, and the transportation and assembly of TEMPS, exact cost estimates must be based on individual requirements. The costs of tests of durations shorter than one year are not necessarily proportional to the 1.0 to 1.5 million dollar figure. For more information, the DNA Project Officer should be contacted.

3.3.8.4 Reference Information

More detailed information concerning the TEMPS can be obtained from the following:

- "Transportable Electromagnetic Pulse Simulator", DNA Brochure

- "Transportable Electromagnetic Pulse Simulator", Physics International Brochure.

3.3.9 HDL Bicone and REPS

HDL presently has a horizontally-polarized simulator known as the HDL Bicone which uses a 1.8 MV RES-I pulser built by Physics International. The simulator is similar in shape to the TEMPS with the following parameters:

Length	300 m
Antenna Diameter	9 feet
Resistive Loading	At ends of tapered section

The existing simulator will be replaced by a system known as REPS (Repetitive Electromagnetic Pulse Simulator) being built by Physics International. The antenna will be very similar to the existing antenna. The pulser will be a single TEMPS type Marx with a self-breakdown, gas insulated output switch and gas dielectric peaking capacitors. The pulser will be capable of firing continuously for up to 6 hours at an output of 1.0 MV and a repetition rate of one pulse per 4 seconds. The pulser output can be increased to approximately 1.3 MV in single shot mode. The pulse risetime will be about 4 ns.

3.3.9.1 Administrative Data

The system will be installed at HDL by January 1974. For more information, contact the HDL Project Officer:

Mr. William Petty
Telephone: 703-664-3691

3.3.10 Martin Marietta Long Wire

The Martin Marietta Long-Wire facility is located at Orlando, Florida. The repetitive-pulse, horizontally-polarized simulator was designed and constructed by the Martin Marietta Corporation and is available for immediate use. Martin Marietta provides instrumentation, data reduction services and data analysis.

The antenna, shown in Figure 3.64, is 1,000 feet long and 43 feet above the ground. It is powered by two 125-kV power supplies. Corona rings are used to minimize corona losses. The spark gap uses a mixture of 6 percent oxygen and 94 percent nitrogen, under pressure (50 to 5000 psi). By varying the pressure, the spacing of the gap, the charging resistance, and the voltage, it is possible to vary the pulse repetition frequency, the amplitude of the radiated field, and the risetime of the pulse.

The pulse risetimes can be varied from 5 to 20 nsec, and the pulse widths can be varied from 100 to 700 nsec. Maximum peak E-field intensity is 1,100 V/m at a point 100 feet from the antenna. Repetition rates of 10 pulses per second are possible.

Peak electric and magnetic fields are plotted in Figure 3.65 as functions of distance from the simulator.

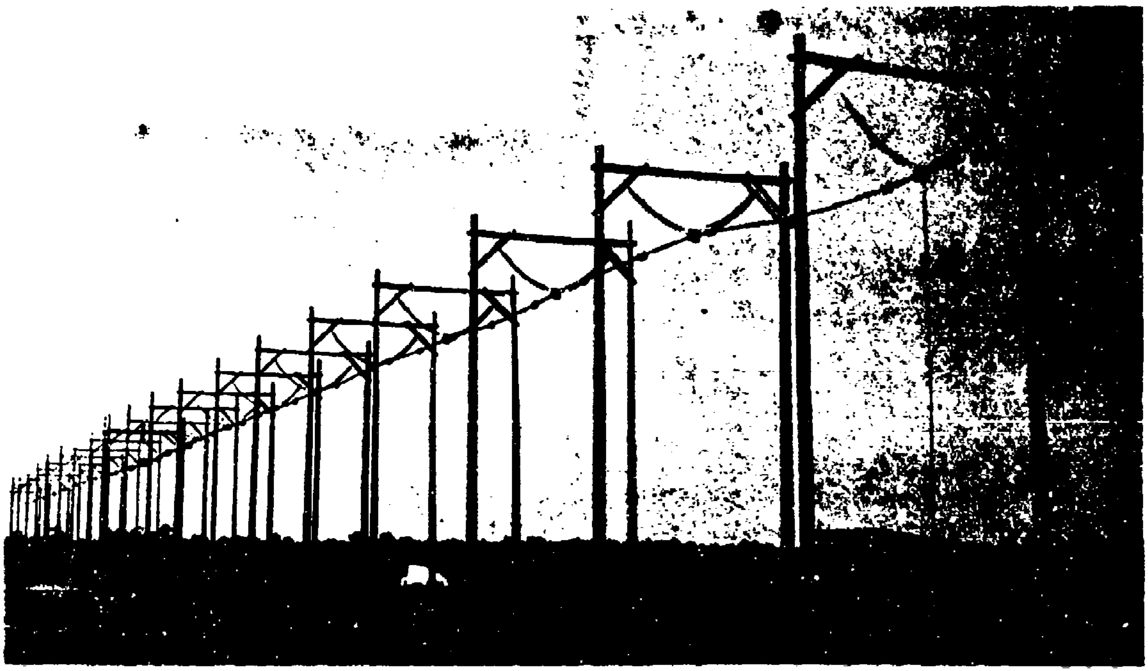


Figure 3.64
1000 Foot Long, Resistively Loaded Spark Gap Excited EMP Facility

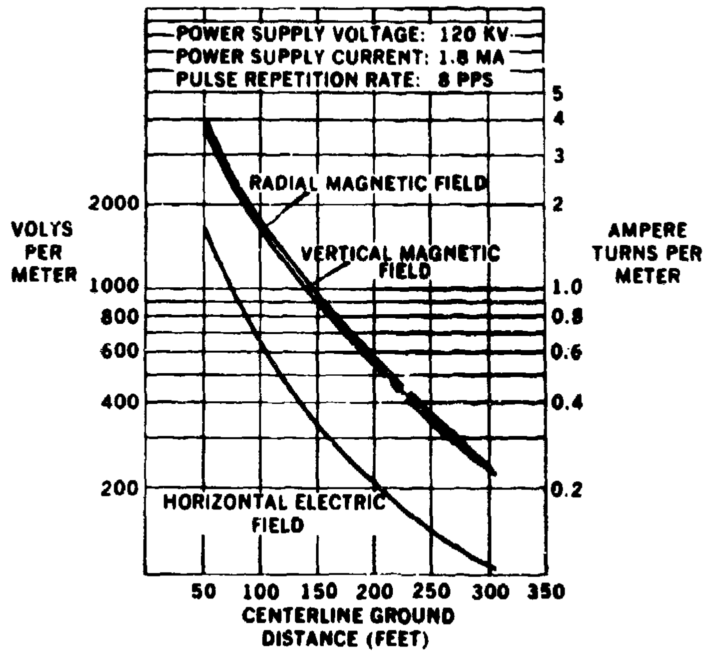


Figure 3.65
Principal Field Vector Amplitude vs Range At 5 Feet Above the Ground

A summary of the physical and electromagnetic characteristics of the Martin Marietta Long-Wire is given in Table 3-7.

TABLE 3-7

Special Test Long-Wire Pulse Facility Characteristics

Horizontal dipole with discrete resistive loading	
Height above ground	43 feet
Length of each dipole half	511 feet
Antenna diameter	Tapered 12 inches to 4 inches
Azimuth beamwidth	60 degrees
Excitation - Spark gap between two half dipoles	
Maximum voltage across gap	20 to 250 kV
Gas pressure in gap	1 to 200 psig
Gas type	94% N_2 and 6% O_2 mixture
Gap electrode separation	3/8 inch to 2-3/8 inches
Line charging power supplies (one per half dipole)	0 to +250 kV (west)
Transmission characteristics - Field intensity waveshape	
Risetime	5 to 20 x 10^{-9} second
Pulse width	700 ns (radial H field)
Decay	Exponential
Repetition rate	0 to 50 pps (limited to max of 10 pps above 240 kV)

3.3.10.1 Administrative Data

For information on rental costs, the interested party should contact:

Research & Technology Marketing
MP-120
Martin Marietta Corporation
Orlando, Florida 32805

3.3.10.2 Reference Information

Further detail concerning the Martin Marietta system may be found from the following:

- "ELECTROMAGNETIC PULSE", Brochure or Martin Marietta Report OR-6981-14B, January 1969.

- "Electromagnetic Pulse Handbook For Missiles and Aircraft In-Flight", SC-M-710346, Sandia Laboratories, September 1971.

3.3.11 Sandia Long-wire Facility

The Sandia Long-Wire was built by Sandia Laboratories for AFWL and is located on Kirtland AFB, New Mexico.

The Sandia Long-Wire Facility is illustrated in Figure 3.66 and 3.67. It is a physically tapered line which is 12 inches in diameter in the center and 4 inches at the end. The larger diameter in the center results in a greater field, but this is too cumbersome to handle over the

Figure 3.66 Sandia Long Wire Facility

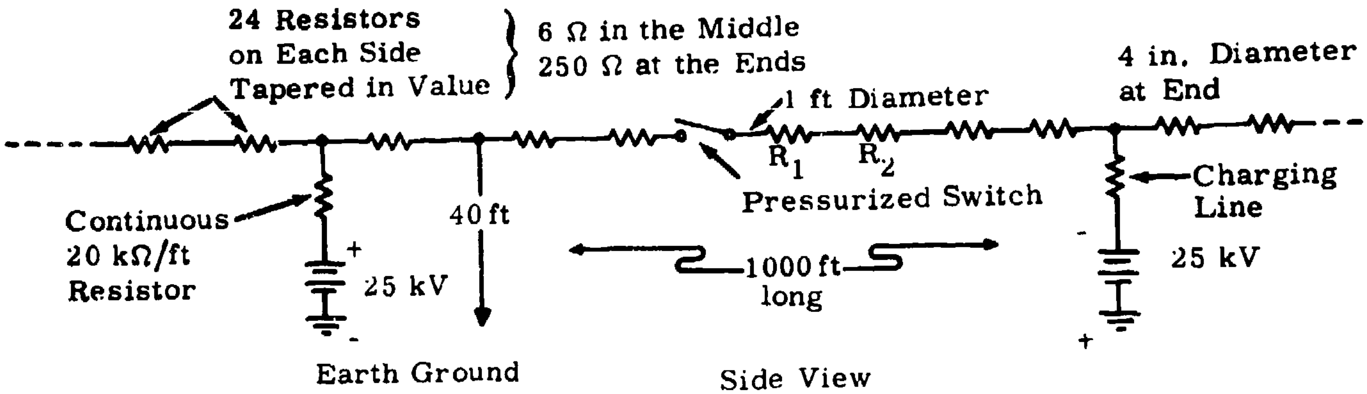


Figure 3.67 Sandia Long-Wire Electric Diagram

1000 foot length of the antenna. The peak magnitude of the field is determined by the center section of the antenna. The antenna is electrically tapered at 20 foot intervals by carbon resistors. There are 24 resistors on each side varying from 6 ohms to 250 ohms. The antenna is charged by 20 k ohm/ft charging lines. These lines are made of lossy material to prevent radiation. They are located 100 feet from the center of the antenna. Two 25 kV generators, connected in series with an earth return, are used to charge the antenna.

The dry nitrogen pressurized switch is set at about 35 psi and breaks down automatically at about 30 kV, producing 20 pps. The risetime of the switch is about 250 nsec. Except for higher magnitudes in early times due to the fast risetime, the waveshapes are similar to the ground interacted waveshapes. There are only slight differences due to finite earth ground conductivity.

The Sandia Long-Wire antenna is a low-level facility and produces an E_z component (horizontal) of about 400 V/m at 50 ft on the centerline, 5 ft off the ground. This component is largely cancelled after 10 nsec. The collapse of the static E_z field provides the equivalent of a step function, and this can be used as a diagnostic tool on systems which are not too large (less than 60 ft) and which respond to the electric field. This type of facility is more appropriately used for systems which are on the surface of the earth.

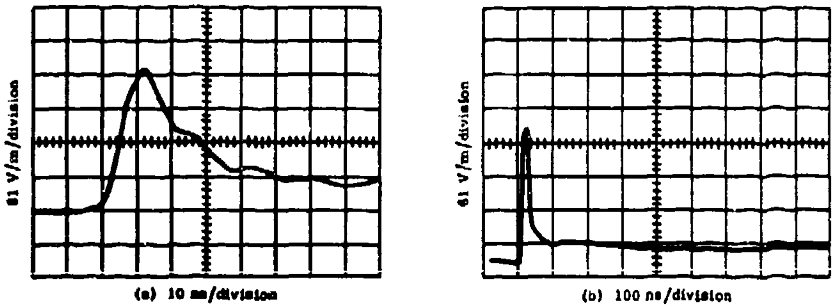
The electric field (E_z) at 50 ft out on the ground plane is shown in Figure 3.68. The upper frequency cutoff of the measurement device was

35 MHz (3 dB point), which limited the peak magnitude. The static field is displayed after switch closure by the measuring equipment.

3.3.11.1 Administrative Data and Reference Information

For further information about this facility contact Mr. R. L. Parker at Sandia Laboratories in Albuquerque, New Mexico, or consult the following:

- "Electromagnetic Pulse Handbook For Missiles and Aircraft In Flight", SC-M-710346, Sandia Laboratories September 1971.



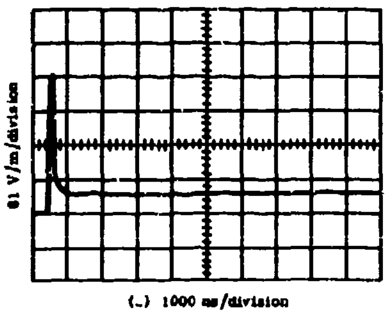


Figure 3.68

Electrical Field Measurement on the Center (OC = 0) 50 Feet Out (OUT = 50) and 99 Inches Abcve Earth ("E" Horizontal to Earth and Parallel to Long-Wire)

3.3.12 LASL Delta Function Generators

The Los Alamos Scientific Laboratory (LASL) is presently operating two delta function generators which produce very fast rise and fall time (or short) pulses. One of the generators produces horizontally polarized electric fields, the other generates vertically polarized electric fields. The vertically polarized facility is presently in Hawaii and will be returned to LASL in early 1974. Although the device may be transported, the job is laborous and expensive; the generator is basically a permanent one at LASL. The horizontally polarized generator is permanently installed at Kirtland Air Force Base.

Unlike EMP simulators, LASL's delta function generators have not been extensively used for detailed transfer function studies of airplanes' internal responses. Rather, they have been used to determine distortion in EM wavefronts caused by the presence of in-flight airplanes. This type of experiment is performed by measuring the fields at points near the generator and with probes mounted outside the airplane. Figure 3.69 shows the horizontally polarized generator in this type of test configuration. The pulse is emitted from the diverging horn plates and is measured both at the airplane and with a sensor mounted on the pole at the right hand side of Figure 3.69.

Figure 3.70 shows the equivalent circuit for the vertically polarized generator. In this case, only the top horn plate diverges. The lower horn plate serves as a ground plane which is mounted on the platform floor. The capacitors are charged to $\pm$ 120 kV. The pulser is fired by a sudden release of gas pressure in the spark gap.

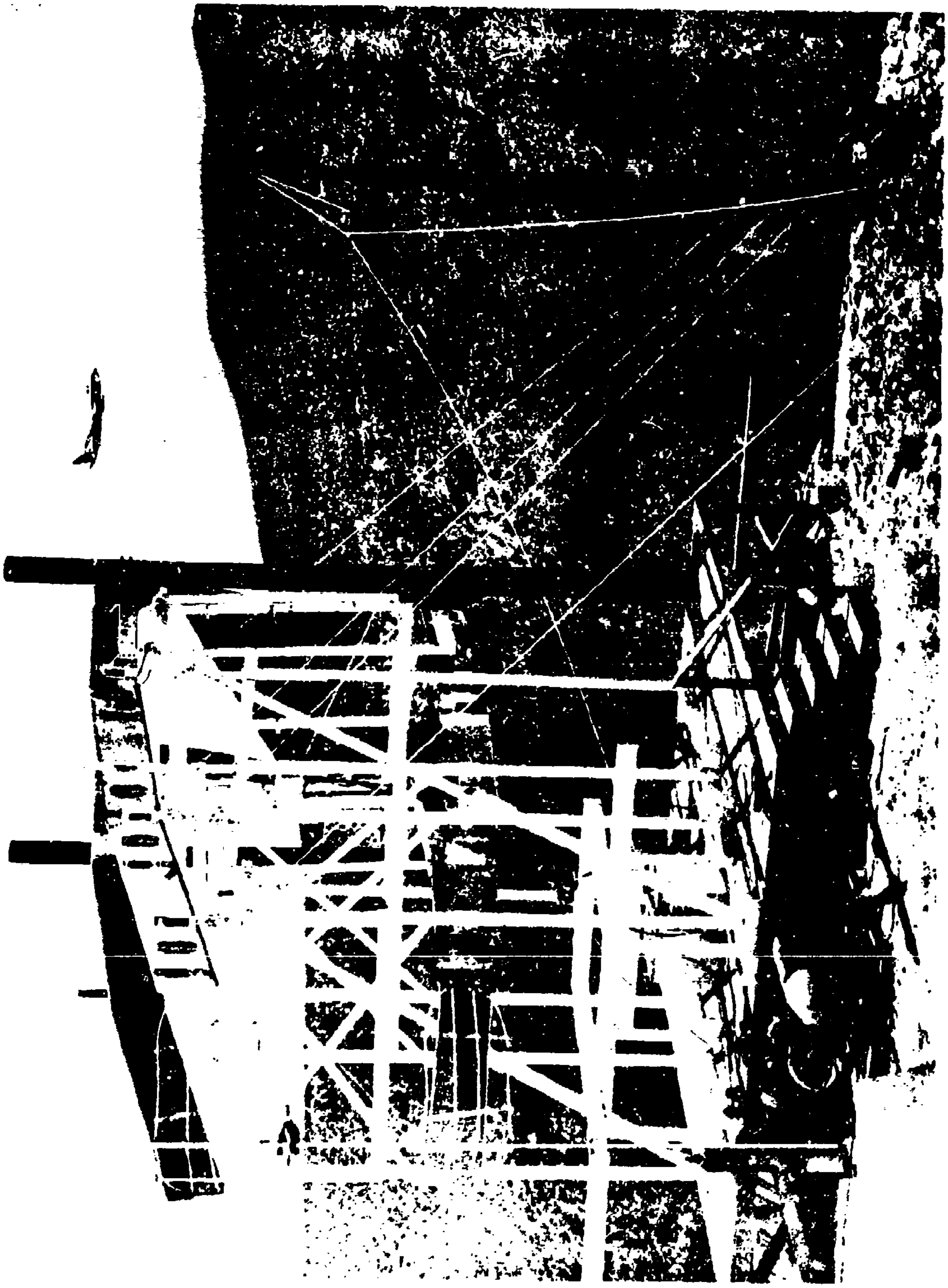


Figure 3.69 Delta Function Generator

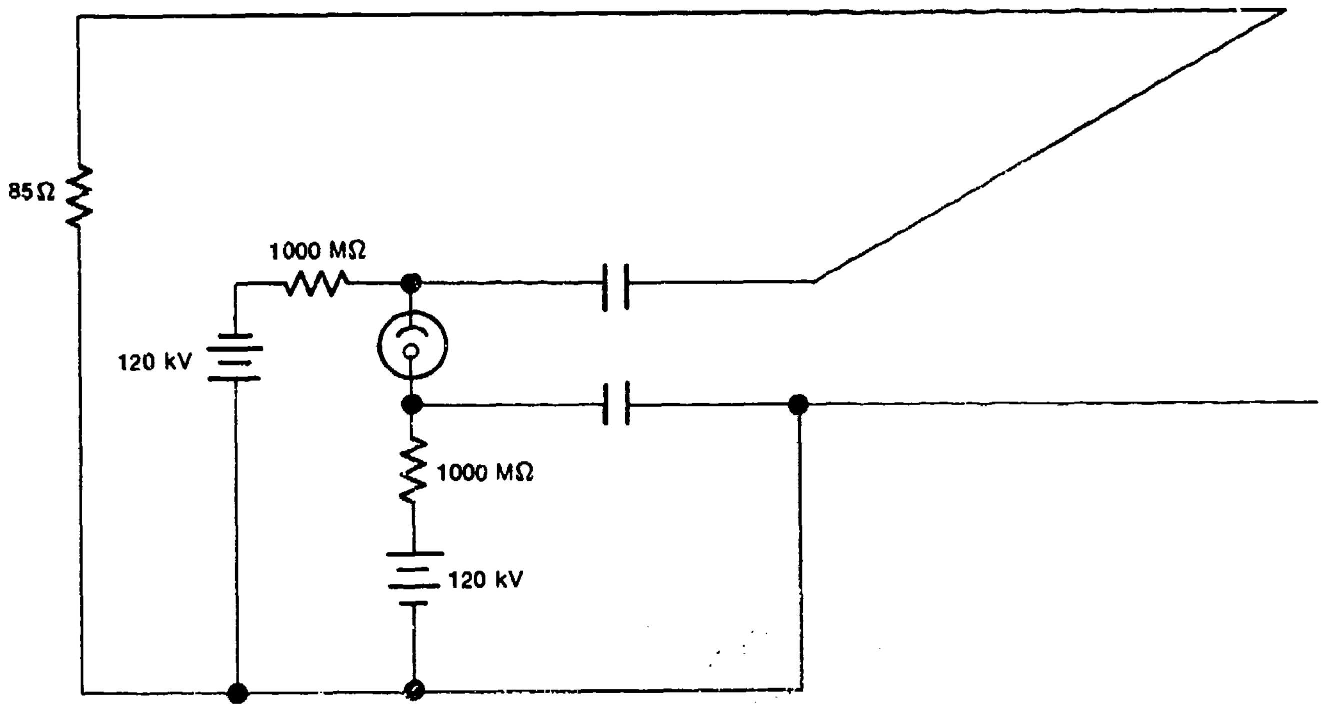


Figure 3.70 Delta Function Generator Circuit Diagram

The pulser for the horizontally polarized generator is of the same design except that the capacitors are charged to only ±60 kV.

Instrumentation used during the tests generally consists of magnetic field probes and fast risetime oscilloscopes. Units have been designed for the scopes which automatically print on the photograph the vertical scale and the clock-time at which the pulse was recorded.

A typical pulse shape from the horizontally polarized radiator is shown in Figure 3.71.

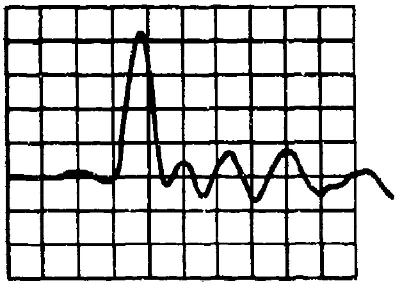


Figure 3.71 Pulse From Horizontally Polarized Generator

The time scale is 2 ns/division; the vertical amplitude scale is not defined. The pulse consists of a large spike with a 10% - 90% risetime of less than 1 ns and an equally fast fall time. Risetimes of 0.8 ns (10% - 90%) are common for this generator. The pulse also shows some late time ringing.

The waveform for the vertically polarized generator is shown in Figure 3.72 where the time scale is 2 ns/division.

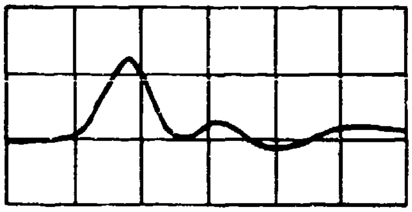


Figure 3.72 Pulse From Vertically Polarized Generator

This pulse has a risetime (10% - 90%) of about 1.2 ns, a typical value for this generator. The pulse also shows a fast decay time and some late time ringing.

The Fourier transform of a mathematical delta function is equal to 1 over all frequencies. The very fast rise and fall times indicate that the pulse transforms would approximate this behavior, giving a nearly constant value over a wide frequency band (up to the GHz range), except for larger components at the late time ringing frequencies. This wide band behavior would make the LASL generators particularly well suited for testing the responses of airplane antenna systems.

Peak field levels, as measured one mile from the source, are 45 volts/m for the horizontally polarized generator and 100 V/m for the vertically polarized generator.

For information concerning schedules and rental costs for the LASL generators, contact the following:

Dr. Ralph Partridge
Los Alamos Scientific Laboratory
Los Alamos, New Mexico
Telephone: 505-667-5255

CHAPTER 4

FUTURE SIMULATORS

4.1 GENERAL

This chapter is intended as a guideline for the costing and scheduling associated with the construction of a new facility. Thus, from this document, it is possible for a potential future EMP facility user to determine if it advantageous or cost effective to utilize existing facilities or to construct his own facility. Availability schedules for existing facilities constantly need to be updated to make this assessment realistic.

4.1.1 Future EMP Test Object Sizes

Four test object sizes were considered as high probability candidates for test in future Navy EMP test programs. A three meter missile, a 10.4 meter Poseidon missile, an A-6 airplane size (16.5 m wing-span x 4.95 m height x 18.1 m length), and a C-130 airplane size (40.3 wing-span x 11.6 m height x 2918 m length), are considered to adequately represent the range of sizes of future Navy EMP test objects. These sizes determine the cost of the facility and the extent of instrumentation.

4.1.2 Temporary Versus Permanent Facility

The major criteria for selecting a temporary versus a permanent facility are whether the test object can be moved to the facility or whether the facility must be moved to the test object, the number and duration of anticipated tests, and the funds available. In this context, temporary implies portable. Major facility items such as pulser, instrumentation, termination, and personnel facilities, may be the same as for a permanent facility but can be relocated and utilized at another site.

However, some items of arrays and ground planes are usually discarded when moving the simulator to another test site. Temporary is defined as a facility used less than six months. A permanent facility is defined as having a lifetime of five years or more. The permanent facility offers advantages in conveniences, operations, and reliability compared to the temporary facility.

4.2 HORIZONTALLY POLARIZED BOUNDED WAVE SIMULATORS, THREAT LEVEL AND LOW LEVEL

4.2.1 General

The major limitations of a horizontally polarized simulator is the interaction of the conducting ground with the electromagnetic wave which makes in-flight simulation difficult. A large dielectric platform should be used to remove the aircraft from the vicinity of the earth. Since the two missile sizes considered can be oriented to vertical positions in a vertically polarized facility but airplanes cannot be easily, only the A-6 and C-130 airplanes will be considered for the horizontally polarized bounded wave simulator.

4.2.2 Basic System Description

Figure 4.1 illustrates the basic array structure, which is a diverging transmission line (conic section) from the pulse generator to a working volume formed by the parallel plate transmission line. Here, essentially a TEM wave will exist which will converge to a terminator via another conic section.

Two sizes of simulators are considered for the A-6 and C-130 airplanes. The largest dimensions of both airplanes determine the size of the simulators. This is 18.1 meters (length) for the A-6 and 40.25 meters (wingspan) for the C-130 aircraft. Three basic dimensions had to be fixed

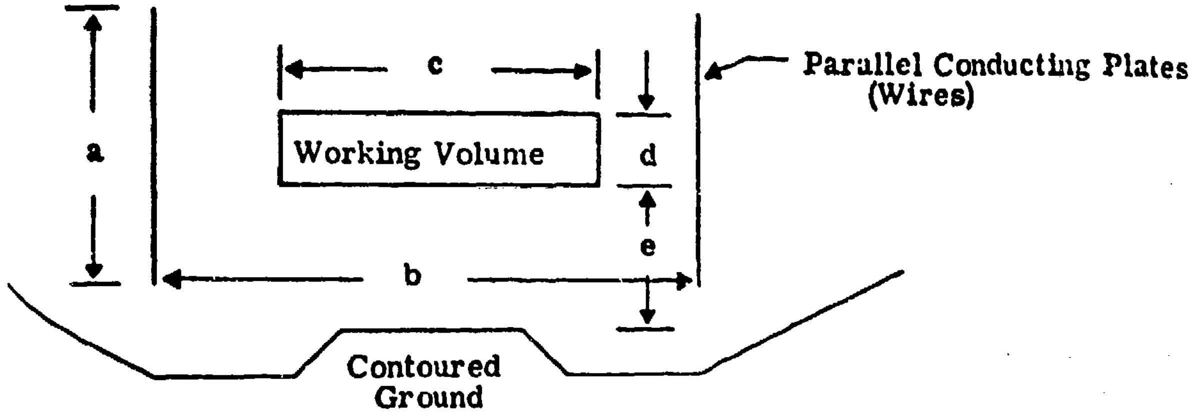


Figure 4.1 End-View Cross-Section of HPS

before further refinement of the HPS design could begin: the parallel-plate spacing, the plate width, and the height of the platform above the working volume (the volume to be occupied by the test airplane). The dimensions of the working volume, c and d, are determined from the maximum size of the aircraft to be tested.

The plate spacing, b, is determined so that test objects in the working volume do not strongly (≤20% effects) react back on the charges moving in the parallel plates. The pulsed excitation of a cylinder in a parallel plate waveguide has been studied (Latham, R. W. and K. S. H. Lee, "Electromagnetic Interaction Between A Cylindrical Post And A Two-Parallel-Plate Simulator, I", Sensor And Simulation Note 111, AFWL, July, 1970.) A comparison was made between the induced currents on the cylinder in a parallel plate as opposed to a free space environment. The results suggest that the ratio $c/b = 0.6$ or $b = 1.6\,c$ provides adequate isolation of the test object from the parallel plates.

The optimal plate width was chosen to make the quasi-static electric fields within the working volume uniform to within 20%. Plots of fields and potential distributions for parallel two plate transmission lines of various plate spacing to plate width ratios, b/a, are available.

These are free space distributions; no conducting ground is present. For a b/a ratio of 2, one can estimate from Figure 4.2 that field strengths will vary by approximately 15% over the working volume (shown by the dashed lines). The ground is expected to add further nonuniformity to the field distribution. On the basis of this evidence, an "optimal" plate width $a = \frac{1}{2} b$ was chosen.

To minimize interaction of the test airplane with the ground, the working volume was located a distance, e, of at least 1/2 the largest dimension of the working volume, from the ground. Thus, the array dimension for the two airplane sizes are as follows:

A-6 Aircraft	C-130 Aircraft
c = 18.1 meters	c = 40.25 meters
b = 29 meters	b = 68 meters
a = 14.5 meters	a = 34 meters
e = 9 meters	e = 20.1 meters

Figure 4.3 illustrates a possible configuration for the A-6 airplane with minimal earthwork.

4.2.2.1 General Support Facilities

The permanent facility usually has refinements such as a tunnel system under the working volume, underground screen-rooms, a high quality ground plane and array, a gantry crane on rails, heating and cooling for the underground facilities, permanent buildings for pulser and terminator, site grading and smoothing, permanent roads and side-walks, permanent utilities, sanitary facilities, and laboratory/machine shops.

The temporary facility does not have these refinements with a resultant loss in efficiency and higher operational and maintenance

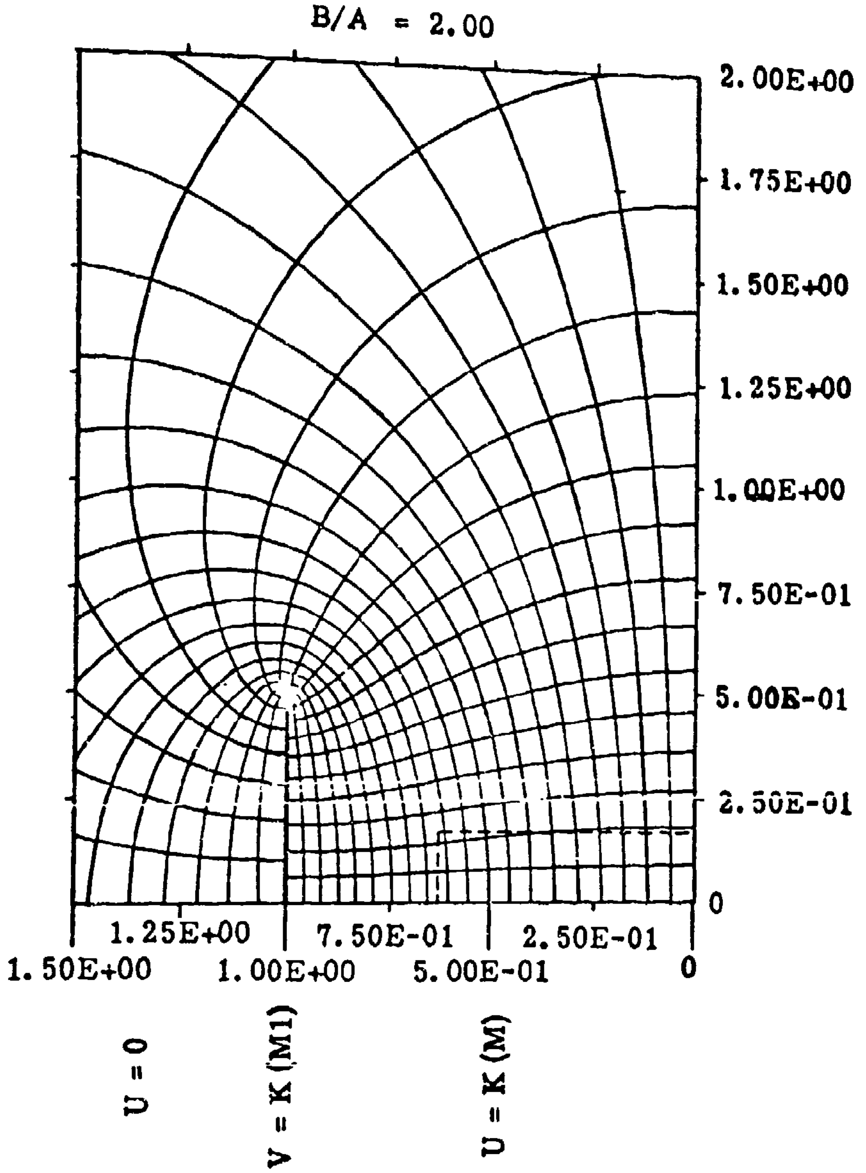


Figure 4.2 Field and Potential Distribution For Parallel Two-Plate Transmission Line, 253.02 Ohms B/A = 2.00

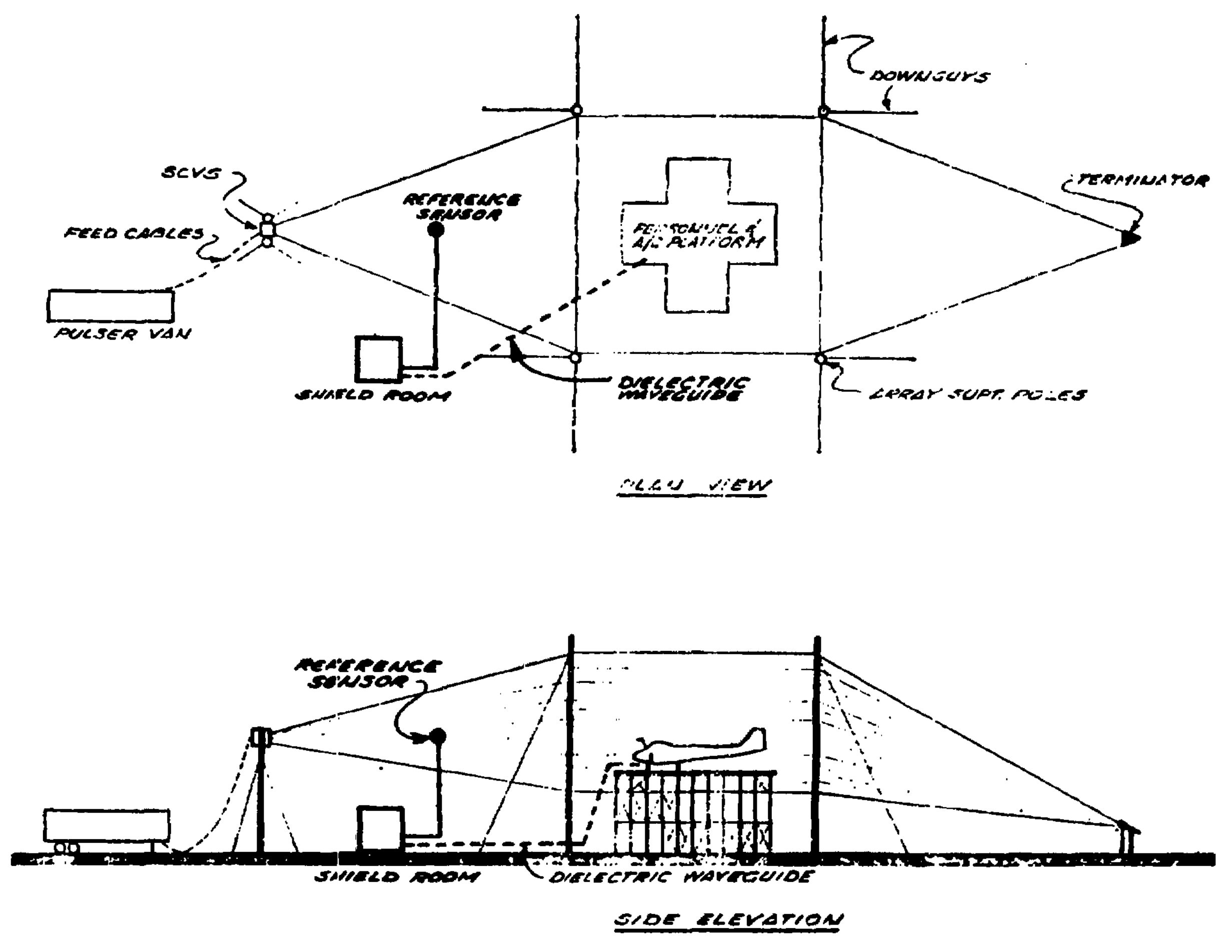


Figure 4.3 A-6 Testing Configuration

costs. Trailers are utilized for screen rooms and personnel facilities. Allowances must be made for personnel being TDY and facility removal and restoration.

Support facilities for permanent and temporary systems are detailed in the cost parameters listed with each facility.

4.2.2.2 Test Stands

The test stand for the A-6 airplane must be 9 meters high and capable of supporting at least 35,000 pounds. The stand for the C-130 must be 20 meters high and capable of supporting at least 75,000 pounds.

4.2.2.3 Environment Characteristics

Typical environment characteristics which set the high voltage pulser, the array, and the terminator performance requirements are listed below:

- Pulse Risetime:
  10-90% ≤ 10 nsec into its nominal load impedance.

- Electric Field Operating Range:
  The electric field shall be continuously variable over a specified operating range (usually from about 10 kV/m).

- Low Electric Field Option:
  In addition to the operating range above, it may be desired to achieve lower discrete peak amplitudes (E_p).

- Charge Voltage Reproducibility:
  The charge voltage to the pulser modules shall be reproducible to ± 1% for a given control setting.

- Repetition Rate:
  Six pulses per hour at the maximum voltage and at least six pulses per hour at lower voltages.

- **Maximum Pulser Voltage:**

  A-6: 1.5×10^6 volts.

  C-130: 3.5×10^6 volts.

- **Field Wave Shape:**

  Double exponential $E(t) = E_o (e^{-\alpha t} - e^{-\beta t})$

- **Decay Time Constant (Td):**

  ~ 500 nsec

- **Waveform Distortion:**

  The amplitude at any instant shall vary no more than $\pm$ 15% from the fitted decay curve during the time from the time of the peak amplitude E_p to twice the decay time constant, $2T_d$.

- **Prepulse:**

  The amplitude of the prepulse shall not exceed 20% of the peak amplitude (E_p). The duration of the prepulse shall not exceed 100 nsec.

- **Reflections:**

  The amplitude of termination reflections shall not exceed 10% of the peak amplitude E_p at any time.

- **Field Non-Uniformity:**

  The field non-uniformity shall not exceed 20%.

- **Wave Front Planarity**

  The wave front distortion shall not exceed 10 nsec.

- **Terminator Reflections:**

  The terminator shall not reflect more than 10% of the incident electric field as measured in the working volume and shall have a lifetime compatible with the pulser.

4.2.3 Instrumentation

The following is a general instrumentation description applicable to all of the facilities described. The extent and cost of these systems shall depend on whether the facility is permanent (fixed quantity dependent on facility size) or whether it is temporary (purchased items minimal, rented items maximized).

4.2.3.1 Data Telemetry Systems

The technique employed in many EMP tests is to electrically isolate the test object from the recording instrumentatio via microwave data telemetry systems. These provide 40 dB dynamic range and 10 kHz up to 250 MHz bandwidth, operating over a range of up to 300 feet using dielectric waveguide. These systems usually are arranged in groups of 1, 4, or 10 channels.

The 10-channel microwave systems are capable of simultaneously transmitting ten channels of data from the working volume to the screen room. This system provides a method of transmitting data from the test item to the screen room through a non-conductive path which is immune to perturbations from the electromagnetic environment. The system consists of a battery-operated transmitter, a dielectric waveguide, and a receiver in the screen room. The system is fully shielded from the electromagnetic environment and all internal switching is done pneumatically. Connection to the test item is made by a 30-inch-long Hipernom bellows which shields the signal cables from environment pickup.

Hard-wire systems are used primarily to gather field sensor data by direct connection to the trace-recording oscilloscopes. The basic problems with conventional cables now in use for EMP measurements are:

1) Bandpass of cables and connectors is not always flat for the frequency range of interest;

2) Noise pickup; and

3) Distortion of the EM environment being measured.

Scopes in isolated screen boxes are often utilized for these measurements. For particular application, the decision to use or not use cables is based on interaction with environment, transmission distance, bandpass required, versatility required, equipment availability, and cost. Cables offer advantages on short lengths by being relatively inexpensive, having wide pandpass with respect of a telemetry system, having a transfer function that is stable and easily determined, having few installation problems, and being very flexible.

4.2.3.2 Data Recording Systems

The conventional oscilloscope/camera combination continues to be the single most satisfactory device for the recording of high-speed transients. Its bandwidth far exceeds that of any other conventional recording method.

The limited dynamic range of approximately 30 dB in turn reduces the required bandwidth recording time product. Data are generally taken on one oscilloscope at varied time base settings or with time tied multiple scopes on one channel. The different traces are tied together in data reduction processes.

4.2.3.3 Shielding Enclosures - Permanent Installation

In a permanent installation, doubly shielded underground rooms usually house the diagnostic instrumentation equipment. The inner and outer walls are of all-welded metal construction and are fully isolated by a 4-inch air space. All signal cables from the working volume are routed through an entry room.

The shield room is accessible through air-sealed sliding doors. Shielding effectiveness is achieved from pressure applied to two mating tinned surfaces. Compressed air is used to maintain sealing pressure on the sliding doors.

Power service to the shield room is provided external to the signal cable duct so as to prevent interference. A master switch box located outside routes power through filters to the power distribution panels in the shield room. Electrical outlets for rack power are located under the floor; power for test equipment is provided in the form of power strips along each wall.

4.2.3.4 Shielded Enclosures - Temporary Installation

The instrumentation systems can be located within a shielded van. The shielded enclosure is a double-walled, all welded, and fully isolated unit, usually seven feet wide by nine feet high by thirty-eight feet long. Standard methods are used to assure EM integrity.

The enclosure has a 100 dB magnetic attenuation at 15 kHz, 100 dB electric attenuation from 1 kHz to 10 GHz, and 120 dB plane wave attenuation from 1 MHz to 10 GHz. Experience has shown these specifications to be sufficient for instrumentation shielding.

Small screen boxes with battery operated scopes may also be required for remote measurements. These screen boxes will have the same attenuation specifications as the shielded van.

4.2.3.5 Command and Control (C&C) Systems

Command and Control (C&C) and Timing and Firing (T&F) systems are used to control and monitor pulse charging and firing, arm oscilloscopes, open and close camera shutters, and actuate selected systems onboard the test object at preselected times. Such systems in use range from pneumatic controls (for electrical isolation) to laser triggering systems.

4.2.4 Cost Estimates

Tables 4-1 and 4-2 present the estimated costs breakdown of the two sizes of horizontally polarized bounded wave simulators examined. The cost figures are estimates based on past EG&G experience in design and construction of EMP simulators. They are not based on detailed design of the specific simulators listed. The actual costs could vary significantly from the estimates shown depending upon the details and sophistication of an actual design.

A temporary version of the 68-meter simulator is not shown since the investment required does not seem justified for a one-time-use facility.

4.3 VERTICALLY POLARIZED BOUNDED WAVE SIMULATORS, THREAT LEVEL AND LOW LEVEL

4.3.1 General

Vertically polarized simulators have been extensively used in EMP test evaluations and are well known in terms of electromagnetic characteristics. Since the two airplane sizes considered cannot be oriented easily about their roll or pitch, then only the normal horizontal position of these airplanes will be considered.

4.3.2 Basic System Description

Array

Figure 4.4 illustrates the basic array structure and working volume dimensions for the four sizes of test vehicles. The following table gives the approximate array dimensions to assure good field uniformity over the test object and an acceptable minimal interaction of the array with the test object.

Test Object	h	W	ℓ	s	d
C-130	20	40	40	74	10
A-6	9	18	18	33	5
Poseidon	16	32	32	59	8
3 Meter Missile	5	10	10	19	3

Table 4-1 68-Meter Horizontal Bounded Array Costs
(Permanent Facility Only, Estimated Costs in Thousands)

			Permanent Facility
I.	BASIC FACILITY		
	1.	Site Preparation	
		A. Soil Studies	5
		B. Surveys	10
		C. Earth work*	100
		D. Roads, Parking Areas	50
		E. Fencing	25
		F. Utilities	60
		• Power	
		• Water	
		• Sanitation	
		G. Taxiways*	200
		SUBTOTAL	450
	2.	Buildings	
		A. Pulser Building (50' x 75')	70
		B. Instrumentation Building (50' x 75')	70
		C. Shield Room (Double wall, 30' x 40')	150
		D. Administration Shelters	40
		E. Test Structures (foundations, pedestal, etc.)	400
		F. Communications, Warning	10
		G. TV Surveillance	30
		H. Cable Conduits	15
		SUBTOTAL	785
II.	SIMULATOR		
	1.	Transmission Line	
		A. Plates	80
		B. Plate Suspension	200
		C. Input Transition Gas Box	30
		D. Termination	30
		SUBTOTAL	340

*Varies with sites, general estimate only.

Table 4-1 (continued)

				Permanent Facility
	2.	Pulse Generator		
		A.	Basic Pulser (4MV, Pulsepak Type)	400
		B.	Low Voltage Equipment (Pulser & Transition)	50
		SUBTOTAL		450
	3.	Instrumentation		
		A.	Microwave System (Two four channels)	175
		B.	Pneumatic Control	15
		C.	Sequencer	15
		D.	Recording Equipment	70
			• Scopes	
			• Camera Controls	
		E.	General Equipment	50
		F.	Sensors	30
			• Environment	
			• Test Item	
		SUBTOTAL		355
III.	PROJECT CONTROL			
	1.	Design and Management		
		A.	Site Engineering (preliminary)	10
		B.	Facility Design	40
		C.	Simulator Design	
			• Array	50
			• Instrumentation	50
		D.	Documentation Support	100
		E.	Project Management	175
		SUBTOTAL		425
	2.	System Integration and Checkout		
		A.	In-house support (preliminary)	20
		B.	Integration and Checkout	75
		C.	Field Mapping	50
		D.	QA	50
		SUBTOTAL		195
IV.	TOTAL FACILITY COSTS			$3,000
V.	TOTAL ESTIMATED CONSTRUCTION TIME (FROM CONTRACT AWARD) -- 18 MONTHS			

Table 4-2 29-Meter Horizontal Bounded Array Costs (Estimated Costs in Thousands)

	Permanent Facility	Temporary Facility
I. BASIC FACILITY		
1. Site Preparation		
A. Soil Studies	5	0
B. Surveys	10	0
C. Earth Work*	50	0
D. Roads, parking areas	30	5
E. Fencing	13	2
F. Utilities	40	5
• Power		
• Water		
• Sanitation		
G. Taxiways*	50	0
SUBTOTAL	198	12
2. Buildings, etc.**		
A. Pulser Building (50' x 50')	40	2
B. Instrumentation Building (40' x 60')	40	
		0
C. Instrumentation Shelter (above ground)	--	20
D. Shield Room (double wall, 25' x 30')	100	0
E. Administrative Shelters	30	2
F. Test Structures (foundations, pedestal, etc.)	50	25
G. Communications, Warning	5	5
H. TV Surveillance	20	0
I. Cable Conduits	15	0
SUBTOTAL	300	54
II. SIMULATOR		
1. Transmission Line**		
A. Plates	30	10
B. Plate Suspension	60	30
C. Input Transition Gas Box	20	--
D. Termination	30	5
SUBTOTAL	140	45
2. Pulse Generator		
A. Basic Pulser (T7 Pulser)	220	220
B. Low Voltage Equipment	50	0
		0
SUBTOTAL	270	220

*Varies with sites, general estimate only

** Life cycle (design, shipment, upkeep) costs foı temporary facilities are not included.

Table 4-2 (continued)

	Permanent Facility	Temporary Facility
3. Instrumentation		
A. Microwave System	85 (4 channels)	23 (1 channel)
B. Pneumatic Control	10	0
C. Sequencer	10	0
D. Recording Equipment	40	10 (lease)
• Scopes		
• Camera Controls		
E. General Equipment	30	
F. Sensors	20	6
• Environment		
• Test item		
G. Screen boxes and Inverters	5	5
SUBTOTAL	200	44
III. PROJECT CONTROL		
1. Design and Management		
A. Site Engineering (preliminary)	10	5
B. Facility Design	30	5
C. Simulator Design		
• Array	40	5
• Instrumentation	40	5
D. Documentation Support	80	10
E. Project Management	100	20
SUBTOTAL	300	50
2. System Integration and Checkout		
A. In-house Support (preliminary)	15	5
B. Integration and Checkout	50	5
C. Field Mapping	40	5
D. QA	40	5
SUBTOTAL	145	20
IV. TOTAL FACILITY COSTS	$1, 553	$445
V. TOTAL ESTIMATED CONSTRUCTION TIME (FROM CONTRACT AWARD)	12 months	4 months

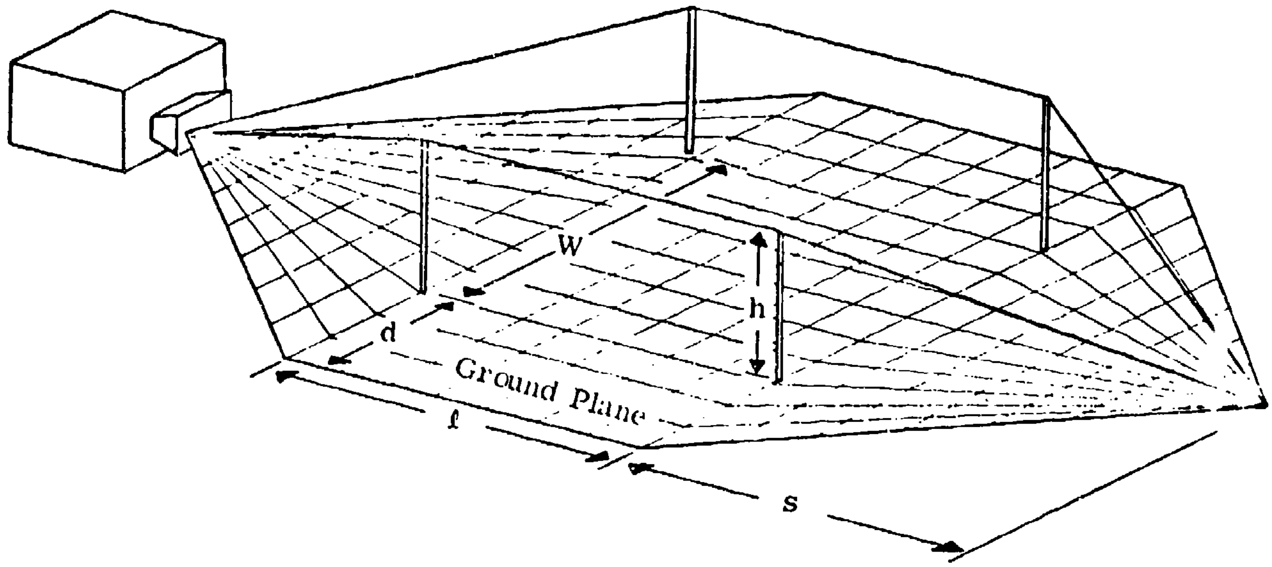


Figure 4.4. Dimensions of Vertically Polarized Array

General Support Facilities

Support facilities for vertically and horizontally polarized facilities are very similar. Refer to Section 4.2 for a description.

Test Stand

The test stands for the missiles and airplanes should be capable of supporting the vehicles near the vertical center of the array. In addition, the missile test stands should be capable of supporting the missiles in either a vertical or horizontal position.

Environment Characteristics

Except for the peak charge voltage amplitude, the environment characteristics are very similar to those given in the previous section. The peak pulser voltages for 50 kV/m fields in the four arrays are as shown below:

Test Object	Array Height	Pulser Charge Voltage (volts)
C-130	20	1×10^6
A-6	9	0.45×10^6
Poseidon	16	0.8×10^6
3 Meter Missile	5	0.25×10^6

4.3.3 Instrumentation

The instrumentation requirements are similar to those as for the horizontally polarized simulator. The extent of the instrumentation systems are detailed in the cost data which follow in Table 4-3.

4.3.4 Cost Estimates

Table 4-3 presents the estimated cost and schedule data for the four simulator sizes in temporary and permanent configurations. Note that no temporary facility is shown for the 20-meter plate spacing. It is assumed that any facility of sufficient size to test a C-130 size airplane would be built only as a permanent test facility due to the sizable investment for a temporary facility. An existing simulator would be used if the cost of a new facility were prohibitive. Permanent facilities are not shown for the two smallest plate spacings (9 and 3 meters). In this case, investment in permanent facilities of such limited applicability does not appear justified. The same explanation of the accuracy of the cost data applies as in the case of the horizontal simulator.

4.4 VERTICALLY POLARIZED LOW LEVEL RADIATING SIMULATORS

4.4.1 General

This section describes the vertically polarized radiating class of low level pulse simulators. These simulators offer the advantage of providing a radiating field with minimal facility/test object interaction and the disadvantage of interaction between the test object and the ground.

Table 4-3 Vertically Polarized Bounded Array Estimated Costs (in Thousands)

	20m Perm.	20m Temp.	16m Perm.	16m Temp.	9m Perm.	9m Temp.	5m Perm.	5m Temp.
I. BASIC FACILITY								
1. Site Preparation								
A. Soil Studies	5		5	0		0		0
B. Surveys	10		10	0		0		0
C. Earthwork[1]	100		90	0		0		0
D. Roads, General Grading[1]	30		25	5		5		5
E. Fencing	10		8	2		2		2
F. Utilities	40		35	5		5		5
• Power								
• Water								
• Sanitation								
G. Taxiways[1]	200		0	0		---		---
SUBTOTAL	395		173	12		12		12
2. Buildings (etc.)[2]								
A. Pulser Building	40		40	5		5		3
B. Instrumentation Building	40		40	---		---		---
C. Instrumentation Shelter	---		---	20		20		10
D. Shield Room	100		100	0		0		0
E. Administrative Shelters	40		40	2		2		2
F. Test Structures	400		100	25		5		5
G. Communications, Warning	5		5	2		5		5
H. TV Surveillance	20		20	0		0		0
I. Cable Conduits	15		15	0		0		0
SUBTOTAL	660		360	54		37		25
II. SIMULATOR								
1. Transmission Line								
A. Top Plate, Ground Plane	60		50	40		25		15
B. Suspension	50		45	35		30		15
C. Input Gas Box	25		20	15		10		---
D. Termination	20		20	10		8		25
SUBTOTAL	145		135	100		73		55
2. Pulse Generator								
A. Basic HV System	200		150	150		75		50
B. Low Voltage System	50		50					
SUBTOTAL	250		200	150		75		50
3. Instrumentation								
A. Microwave System	85[3]		85[3]	23[4]		23[4]		23[4]
B. Pneumatic Control	10		10	0		0		0
C. Sequencer	10		10	0		0		0
D. Recording Equipment	40		40	10		10		5
• Scopes								
• Cameras, Controls								
E. General Equipment	30		30	0		0		0
F. Sensors	20		20	6		6		6
• Environment								
• Test Item								
G. Screen Boxes and Inverters	5		5	10		5		5
SUBTOTAL	200		200	44		44		39
III. PROJECT CONTROL								
1. Design and Management								
A. Site Engineering (prelim.)	10		10	5		2		2
B. Facility Design	25		25	15		5		0
C. Simulator Design								
• Array	40		35	20		5		5
• Instrumentation	40		40	20		5		5
D. Documentation Support	80		60	20		15		10
E. Project Management	100		80	20		15		5
SUBTOTAL	295		250	100		47		27
2. System Integration & Checkout								
A. In-house Support (prelim.)	20		15	5		5		2
B. Integration & Checkout	30		20	5		5		2
C. Field Mapping	35		20	5		5		5
D. QA	35		20	5		5		3
SUBTOTAL	120		75	20		20		12
IV. TOTAL FACILITY COSTS	$2,065		$1,393	$480		$308		$200
V. TOTAL ESTIMATED CONSTRUCTION TIME (FROM CONSTRACT AWARD)	14 months		11 months	4 months	4 months	3 months	3 months	2 months

[1] Varies with sites, general estimate only.

[2] Life cycle (design, shipment, upkeep) costs for temporary are not included.

[3] 4 channels.

[4] 1 channel.

Also, the pulse waveform does not approximate the actual EMP waveshape as well as bounded wave simulators.

A vertically polarized dipole EMP simulator can be used as a comparatively low cost and relatively well understood EMP test facility. It produces only the vertical components of an EMP and has maximum field strengths of the order of 5 x 10^3 volts per meter, and must therefore be considered a low-voltage source for vertical pulses.

4.4.2 System Description

Array

Figure 4.5 illustrates the basic array structure assumed, which is essentially a resistively tapered monopole over a ground plane (see discussion of the AFWL VPD facility in Chapter 3).

The VPD antenna for the Poseidon and C-130 test vehicles is approximately a 30-degree resistively loaded wire cone rising a height of approximately 90 feet. A height of about 45 feet is required for the 3 meter missile and the A-6 airplane.

The low-frequency characteristics of the antenna are enhanced by adding "hoop" wires to connect the eight vertical wires just above each resistor string, by adding crossed diagonal wires between layers of resistor strings, and by adding a "spider-web" top cap. These additions increase the antenna capacitance, and thereby the late time electric dipole moment.

The antenna is supported by wooden telephone poles located on a circumference of about 25 meters in radius for the 90 foot VPD and about 12.5 meters for the 45 foot VPD. The antenna is resistively loaded to give the desired waveshape to the radiated pulse, with the resistance per unit length varying such that the current approaches zero as it approaches the top of the antenna.

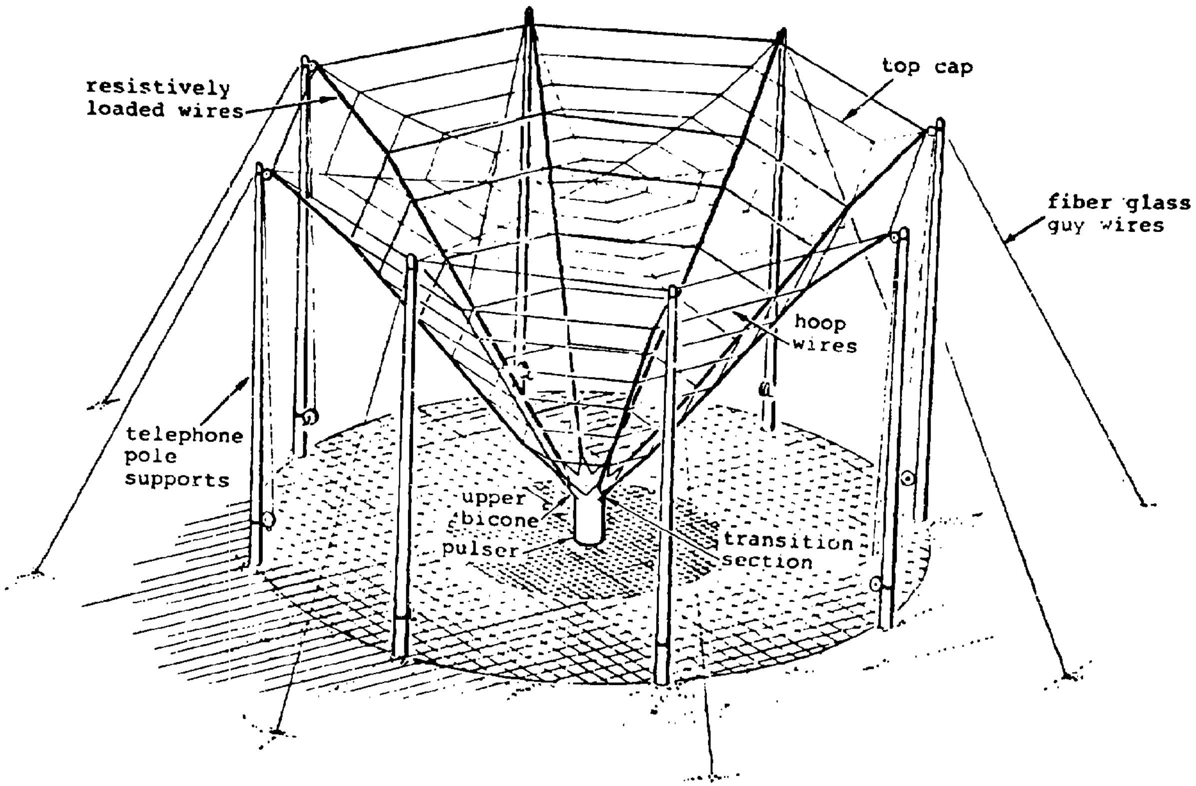


Figure 4.5 VPD Array

4.4.3 Cost Estimates

The following tables present estimated costs for temporary VPD facilities. It is assumed that the primary reason for requiring another VPD (other than the permanent facilities now available) would be to accomplish the EMP simulation at the location of the system thus requiring only a temporary facility.

4.5 HORIZONTALLY POLARIZED LOW LEVEL RADIATING SIMULATOR

A horizontally polarized dipole (HPD) EMP simulator can be a comparatively low cost simulator for providing low level, horizontally polarized E-fields for EMP coupling studies, and as such would complement a vertically polarized dipole (VPD) simulator. An HPD and VPD used as two components of a test facility are an excellent way to divide the EM pulse into vertical and horizontal components for EMP experimentation.

These simulators do not provide a good reproduction of the EMP waveshape due to ground reflections. Also, the test object usually interacts with the ground plane due to close proximity. Thus, test results can have larger error bounds due to those effects, and the simulator should be used to obtain gross coupling information.

The HPD discussed here would consist of the horizontal dipole simulator, a parking pad, an access taxiway for airplanes, various instrumentation and data recording devices, and support facilities. The simulator would consist of a pulser centered in a long-wire cage antenna supported above the ground on a series of telephone poles and resistively terminated and grounded at each end. There would be no ground plane other than the natural earth (or water). Figure 4.6 gives the basic dimensions for the simulator, as well as the coordinates and notation that applies to the discussion.

Table 4-4 90' VPD Estimated Costs

				Temporary Facility
I.	BASIC FACILITY			
	1.	Site Preparation		
		A.	Soil Studies	0
		B.	Surveys	0
		C.	Earth Work*	5
		D.	Roads, Parking Areas	5
		E.	Fencing	2
		F.	Utilities • Power • Water • Sanitation	10
		G.	Taxiways*	25
			SUBTOTAL	47
	2.	Buildings (etc.)**		
		A.	Pulser Building (50' x 75')	20
		B.	Instrumentation Building (underground, 50' x 75')	0
		C.	Instrumentation Shelter (above ground)	20 (trailer)
		D.	Shield Room (double wall, 30' x 40')	0
		E.	Adminstrative Shelters (2 trailers)	2 (lease)
		F.	Test Structures (foundations, pedestal, etc.)***	150
		G.	Communications, Warning	5
		H.	TV Surveillance	0
		I.	Cable Conduits	5
			SUBTOTAL	202
II.	SIMULATOR			
	1.	Transmission Line**		
		A.	Poles	15
		B.	Array	25
		C.	Ground Plane	10
			SUBTOTAL	50
	2.	Pulse Generator		
		A.	Basic Pulser (1.8 MV)	100
		B.	Command and Control System	10
			SUBTOTAL	110

*Varies with sites, general estimate only
** Life cycle (design, shipment, upkeep) costs for temporary are not included
*** Cost for missile type stands; varies depending on test objectives

Table 4-4 (continued)

	Temporary Facility
3. Instrumentation	
A. Microwave System (4 channels)	23
B. Pneumatic Control	5
C. Sequencer	
D. Recording Equipment	15
• Scopes	
• Camera, controls	
E. General Equipment	10
F. Sensors	5
• Environment	
G. Screen boxes and Inverters	5
SUBTOTAL	63
III. PROJECT CONTROL	
1. Design and Management	
A. Site Engineering (preliminary)	2
B. Facility Design	5
C. Simulator Design	7
• Array	
• Instrumentation	
D. Documentation Support	7
E. Project Management	10
SUBTOTAL	31
2. System Integration and Checkout	
A. In-house support (preliminary)	3
B. Integration and Checkout	5
C. Field Mapping	5
D. QA	2
E. Documentation Support	3
SUBTOTAL	18
IV. TOTAL FACILITY COSTS	$521
V. TOTAL ESTIMATED CONSTRUCTION TIME (FROM CONTRACT AWARD)	3 months

Table 4-5 45' VPD Estimated Costs

	Temporary Facility
I. BASIC FACILITY	
1. Site Preparation	
A. Soil Studies	0
B. Surveys	0
C. Earth Work*	0
D. Roads, Parking Areas	2
E. Fencing	2
F. Utilities	3
• Power	
• Water	
• Sanitation	
G. Taxiways*	3
SUBTOTAL	10
2. Buildings (etc.)**	
A. Pulser Building (50' x 75')	10
B. Instrumentation Building (underground, 50' x 75')	0
C. Instrumentation Shelter (above ground)	20 (trailer)
D. Shield Room (double wall, 30' x 40')	0
E. Administrative Shelters	2 (lease)
F. Test Structures, (foundations, pedestal, etc.)	20
G. Communications, Warning	5
H. TV Surveillance	0
I. Cable Conduits	0
SUBTOTAL	57
II. SIMULATOR	
1. Transmission Line**	
A. Poles	8
B. Array	15
C. Ground Plane	5
SUBTOTAL	28
2. Pulse Generator	
A. Basic Pulser (1.8 MV)	100
B. Command and Control System	10
SUBTOTAL	110

*Varies with sites, general <u>estimate</u> only
**Life cycle (design, shipment, upkeep) costs for temporary are not included

Table 4-5 (continued)

	Temporary Facility
3. Instrumentation	
A. Microwave System (2 channel)	23 (1 channel)
B. Pneumatic Control	5
C. Sequencer	
D. Recording Equipment	10
• Scopes	
• Camera Controls	
E. General Equipment	10
F. Sensors	5
• Environment	
• Test Item	
G. Screen boxes and Inverters	5
SUBTOTAL	58
III. PROJECT CONTROL	
1. Design and Management	
A. Site Engineering (preliminary)	2
B. Facility Design	2
C. Simulator Design	5
• Array	
• Instrumentation	
D. Documentation Support	7
E. Project Management	10
SUBTOTAL	26
2. System Integration and Checkout	
A. In-house Support (preliminary)	3
B. Integration and Checkout	5
C. Field Mapping	5
D. QA	2
E. Documentation Support	3
SUBTOTAL	30
IV. TOTAL FACILITY COSTS	$279
V. TOTAL ESTIMATED CONSTRUCTION TIME (FROM CONTRACT AWARD)	2 months

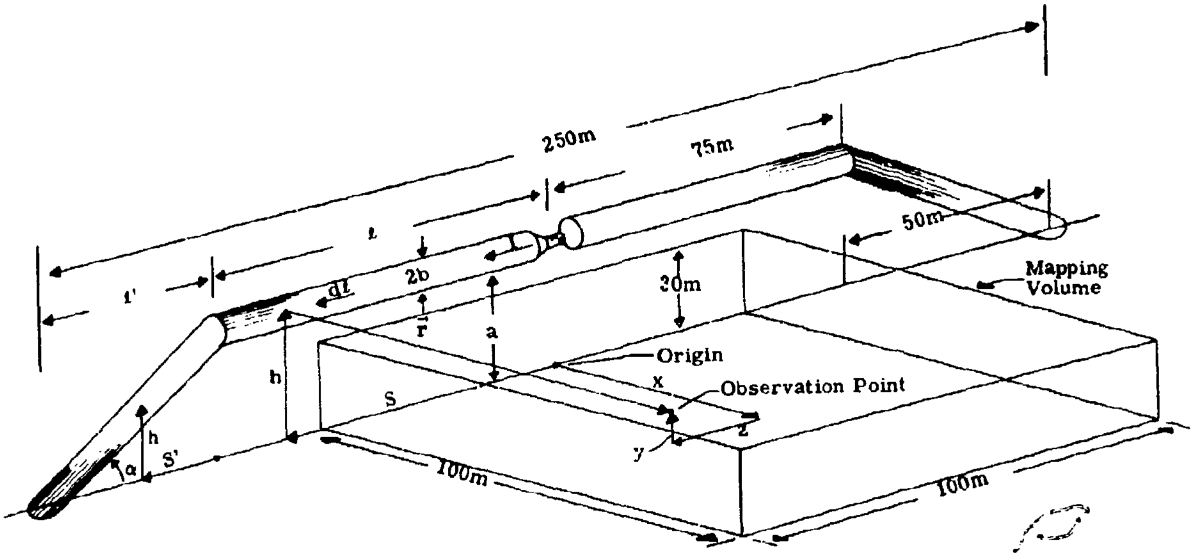


Figure 4. 6.   Basic HPD Antenna Configuration

4. 5. 1   System Description

Array

The bicones on each end of the pulser would be extended with wire conductors until the total bicone diameter is about 15 feet. This yields sufficient clear time for the bicone to radiate the peak energy before the wave is perturbed by the bicone to cylinder transition. The cylindrical antenna would consist of wire conductors held into position by hoops of aluminum tubing with each conductor clamped to hoops. Each hoop would be supported from a catenary, in turn supported from the tops of poles or masts. The entire antenna (and pulser) would be on a pulley system so that it could be winched to ground level.

The antenna should have sloping terminator sections on each end. These sections would have resistors distributed along their lengths and would be designed to minimize antenna ringing. These terminations would be electrically grounded to improve the low-frequency response of the antenna.

Test Stands

Airplanes usually are parked at the ground level, although it would be preferable to raise them approximately one-half airplane height to minimize ground plane interaction. The two missiles require stands to raise them approximately one-half missile height in both horizontal and vertical orientations.

4.5.2 HPD Pulser

Any lightweight pulser can be used in an HPD. In particular, the Pulspak 8000 and 9000 used in EMPRESS and HPD built by Pulsar, the TORUS pulser by Maxwell, or the RES-I or TEMPS pulsers by P.I. are all potential pulsers for use in an HPD.

4.5.3 Environment Characteristics

The EM environments discussions in the earlier descriptions of the AFWL HPD and DNA TEMPS simulators give information on the expected EM performance.

4.5.4 Instrumentation

The instrumentation requirements are similar to those for the vertically polarized radiating simulator. The extent of the instrumentation systems are detailed in the following cost data.

4.5.5 Cost Estimates

The following tables present the simulator breakdown of estimated cost data for the Radiating Horizontally Polarized Simulator, for only a temporary configuration.

Table 4-6 HPD Estimated Cost Breakdown

	Temporary Facility
I. BASIC FACILITY	
1. Site Preparation	
A. Soil Studies	0
B. Surveys	0
C. Earth Work*	0
D. Roads, Park Areas	5
E. Fencing	2
F. Utilities	20
• Power	
• Water	
• Sanitation	
G. Taxiways*	25
SUBTOTAL	52
2. Buildings (etc.)**	
A. Instrumentation Building (underground, 50' x 75')	0
B. Instrumentation Shelter (above ground)	20
C. Shield Room (double wall, 30' x 40')	0
D. Administrative Shelters	2
E. Test Structures (foundations, pedestal, etc.)	50
F. Communications, Warning	5
G. TV Surveillance	0
H. Cable Conduits	5
SUBTOTAL	82
II. SIMULATOR	
1. Transmission Line**	
A. Poles	10
B. Resistors	10
C. Array	15
D. Pulley System	25
SUBTOTAL	60
2. Pulse Generator	
A. Basic Pulser (1.8 MV)	100
B. Command and Control System	10
SUBTOTAL	110

*Varies with sites, general estimate only

**Life cycle (design, shipment, upkeep) costs for temporary are not included

Table 4-6 (continued)

			Temporary Facility
	3.	Instrumentation	
		A. Microwave System (4 channel)	23 (1 channel)
		B. Pneumatic Control	15
		C. Sequencer	15
		D. Recording Equipment • Scopes • Camera Controls	15
		E. General Equipment	10
		F. Sensors • Environment • Test Item	5
		G. Screen boxes and Inverters	5
		SUBTOTAL	58
III.	PROJECT CONTROL		
	1.	Design and Management	
		A. Site Engineering (preliminary)	2
		B. Facility Design	5
		C. Simulator Design	
		• Array	5
		• Instrumentation	5
		D. Documentation Support	5
		E. Project Management	10
		SUBTOTAL	32
	2.	System Integration and Checkout	
		A. In-house Support (preliminary)	3
		B. Integration and Checkout	5
		C. Field Mapping	5
		D. QA	2
		E. Documentation Support	3
		SUBTOTAL	18
IV.	TOTAL FACILITY COSTS		$412
V.	TOTAL ESTIMATED CONSTRUCTION TIME (FROM CONTRACT AWARD)		3 months

4.6 RADIATING VERTICALLY POLARIZED CW SYSTEM

4.6.1 General

The Radiating CW System was developed by EG&G during the SAFEGUARD Communications Agency's EMP Testing Program to obtain transfer functions characterizing the shielding of AT&T microwave stations. As shown in Figure 4.7, an objective was to provide wide area illumination necessary for evaluating the effects of large objects such as the microwave tower and power lines. Figure 4.7 also shows a bounded CW array which characterized shielding of the building walls but could not adequately excite the microwave tower, a very large receiving antenna for the large, low-frequency energy content associated with the EMP spectrum.

4.6.2 System Description

The block diagram , Figure 4.8, shows the Radiating System's components. A swept CW source drives the monopoles via a microwave link and a power amplifier. Transmitting energy to the antennas via a microwave link prevents interaction of cables with the radiated field as would occur if a source-antenna link were used. The three antennas provide vertically polarized radiation over various frequency ranges and are located to provide only 1/r varying far-field illumination at the test object. The table below describes the antenna characteristics. Also, either of the two pulsed radiating antennas described in Section 4.4 may be driven with resulting radiation characteristics similar to those described for the antenna system.

Monopole	Distance From Test Object	Radiated Frequencies
4 m	150 m	5 - 110 MHz
20 m	200 m	0.5 - 5 MHz
100 m	300 m	0.1 - 0.5 MHz

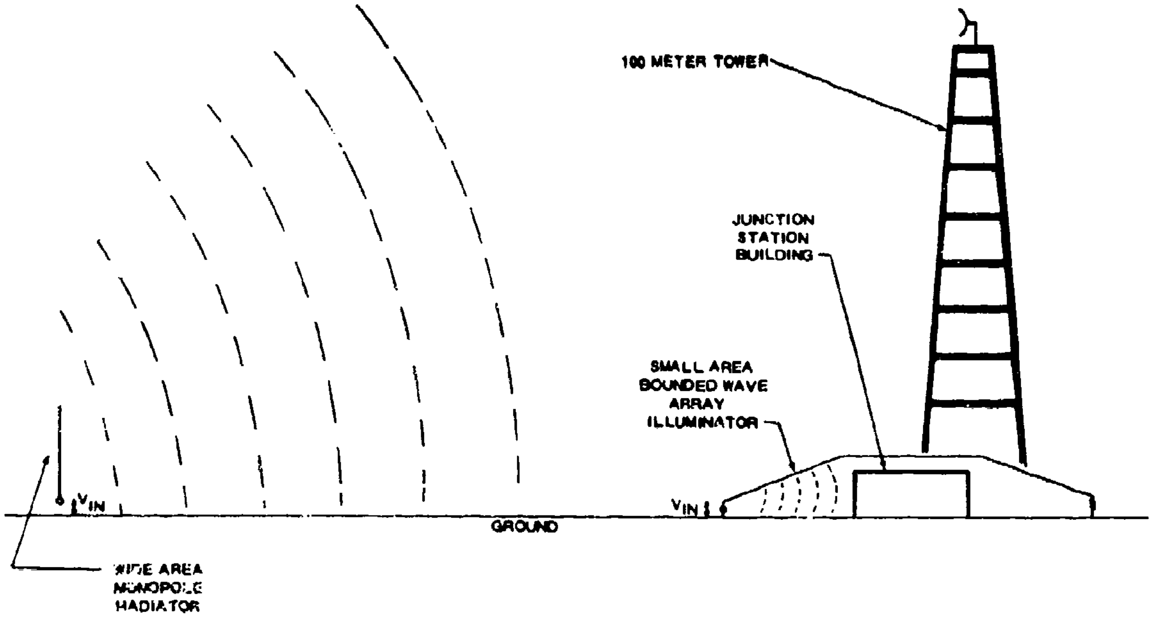


Figure 4.7 Techniques for Evaluating Building Attenuation and Tower Effects

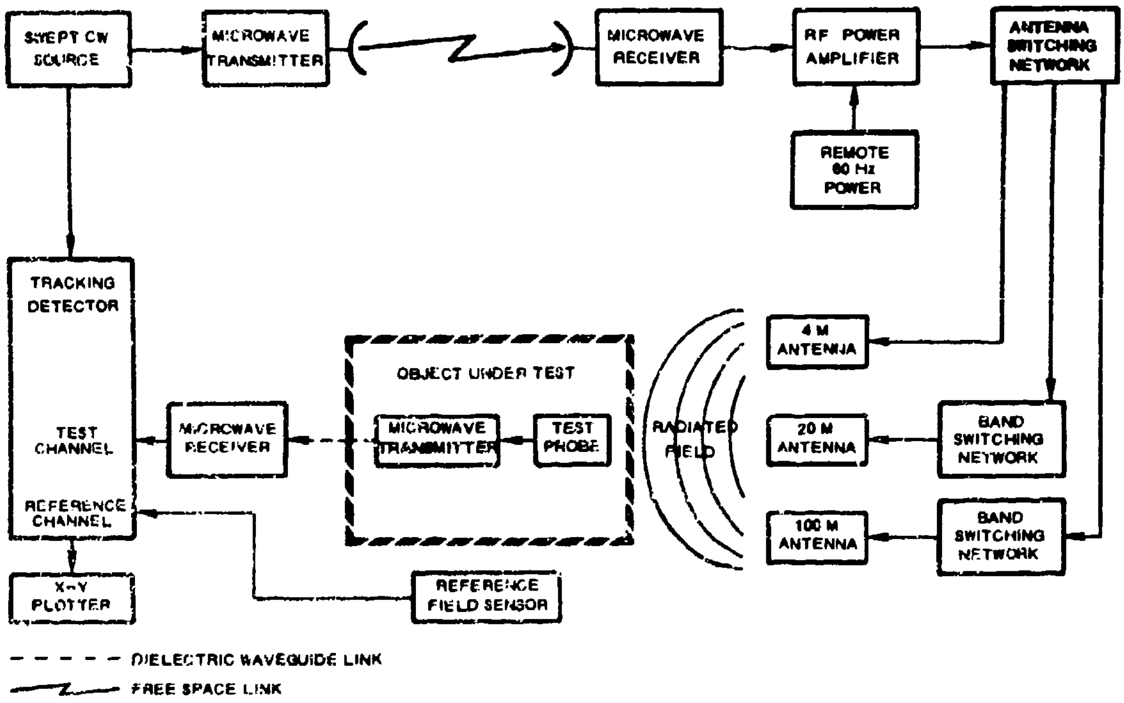


Figure 4.8 Radiating CW System Block Diagram

Remotely controlled multitap inductors in series with the 20 m and 100 m antennas allow efficient radiation over the frequency ranges listed. Transfer functions of a test probe output divided by the output of a permanently stationed reference probe are detected by either an HP or GR network analyzer. Test channel signals are delivered to the network analyzer via a microwave isolation link to prevent extraneous signal pickup from the incident field. The reference probe output indicates incident field strength at the test object. The amplitude, as well as the phase difference of the transfer function of the ratio of the test and reference signals, are recorded on an x-y plotter as a function of frequency from 0.1 - 110 MHz.

4.6.3 Radiating CW System Capabilities

The conditions under which the field strength and sensitivities of the Midlothian CW system were obtained are listed in the table below:

- Monopole radiators used up to third harmonic
- 100 Watt amplifier
- No system resonances, incident field attenuation only
- A -126 dBm threshold, HP Network Analyzer
- Signal/50 ohm noise ratio of 10 dB
- Sensor equivalent area of 0.1 m^2 (MGL-1) for frequencies up to 100 MHz
- Sensor equivalent area of 0.1 m^2 (MGL-2) for frequencies above 100 MHz
- E_{inc}/H_{inc} value of 377 ohms ($\pm$ 3 dB at low frequencies)
- Poor soil conditions ($\sigma \simeq 10^{-2} \frac{\text{MHOS}}{\text{METER}}$, $\epsilon_R \simeq 5$)
- Simple ground plane array

Figure 4.9 shows the lower bounds on radiated field strengths of the various monopoles. These plots are based on the CW system parameter values listed in the table. With the aid of these curves and the values for the minimum detectable signal in the CW system's test channel, one can determine the minimum valid transfer functions obtainable with the system. In this manner, the attenuation measurement capability of the CW system, Figure 4.10 was obtained, again using the listed parameter values. The measurement capability varies from 50 dB at 0.3 MHz to 70 dB at 100 MHz. The use of a GR network analyzer, in place of the HP model, increases the sensitivities plotted in Figure 4.10 by 10 dB and extends the frequency range to 250 MHz. Varying other parameters also modifies these curves. For example, the use of an H-field sensor with an effective area of 1 m^2 increases the low-frequency sensitivity by 20 dB, and the use of a 1 kW amplifier increases the overall curve by 10 dB.

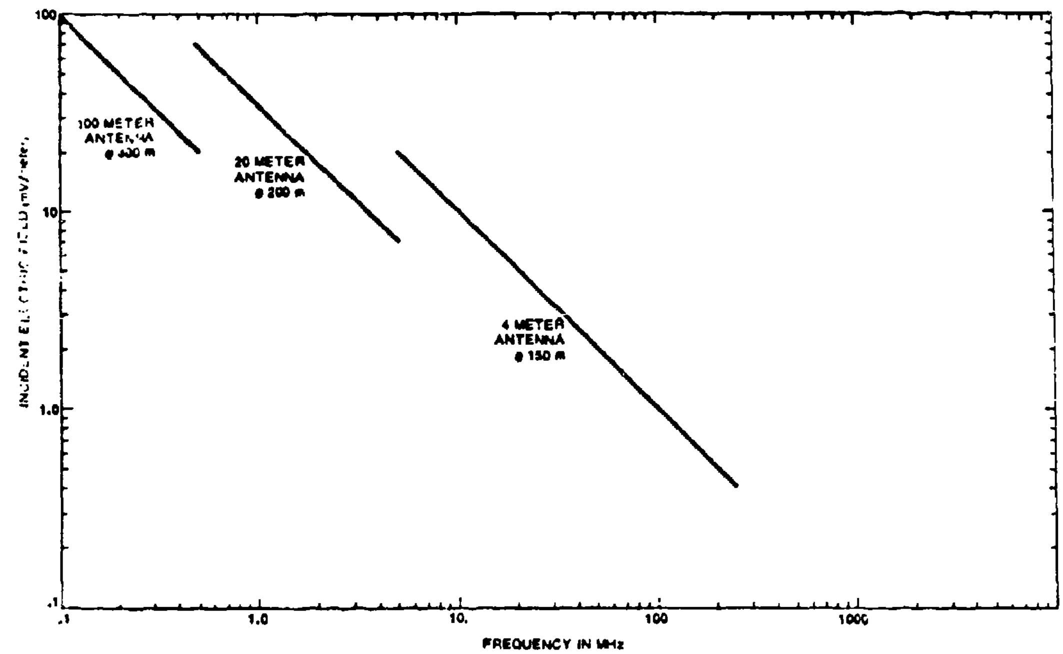


Figure 4.9. Incident Field Strength versus Frequency for 4 m, 20m, and 100 m Antennas

Table 4-7 CW Facility Cost Estimates

				Permanent Facility
I.	BASIC FACILITY			
	1.	Site Preparation		
		A.	Roads, Parking Area	5
		B.	Fences	2
		C.	Utilities	3
			SUBTOTAL	10
	2.	Buildings (etc.)		
		A.	Shielded Van	15
		B.	Communications	5
			SUBTOTAL	20
II.	CW SYSTEM			
	1.	Radiating Components		
		A.	Antennas	8
		B.	Transmitter	6
		C.	Microwave Frequency Link	7
		D.	Switching and Tuning System	8
			SUBTOTAL	29
	2.	Instrumentation		
		A.	Network Analyzer and Plotter	10
		B.	Command and Control Panel	6
		C.	Microwave Isolation Link	10
		D.	Cables and Connectors	3
		E.	Preamps	2
		F.	Miscellaneous	5
			SUBTOTAL	36
III.	PROJECT CONTROL			
	1.	Design and Management		
		A.	Site Planning	3
		B.	Documentation Support	1
		C.	Project Management	3
			SUBTOTAL	7
	2.	System Integration and Checkout		
		A.	Field Mapping	2
		B.	System Setup and Checkout	4
			SUBTOTAL	6
IV.	TOTAL FACILITY COSTS			$ 108
V.	TOTAL ESTIMATED CONSTRUCTION TIME (FROM CONTRACT AWARD)			3 months

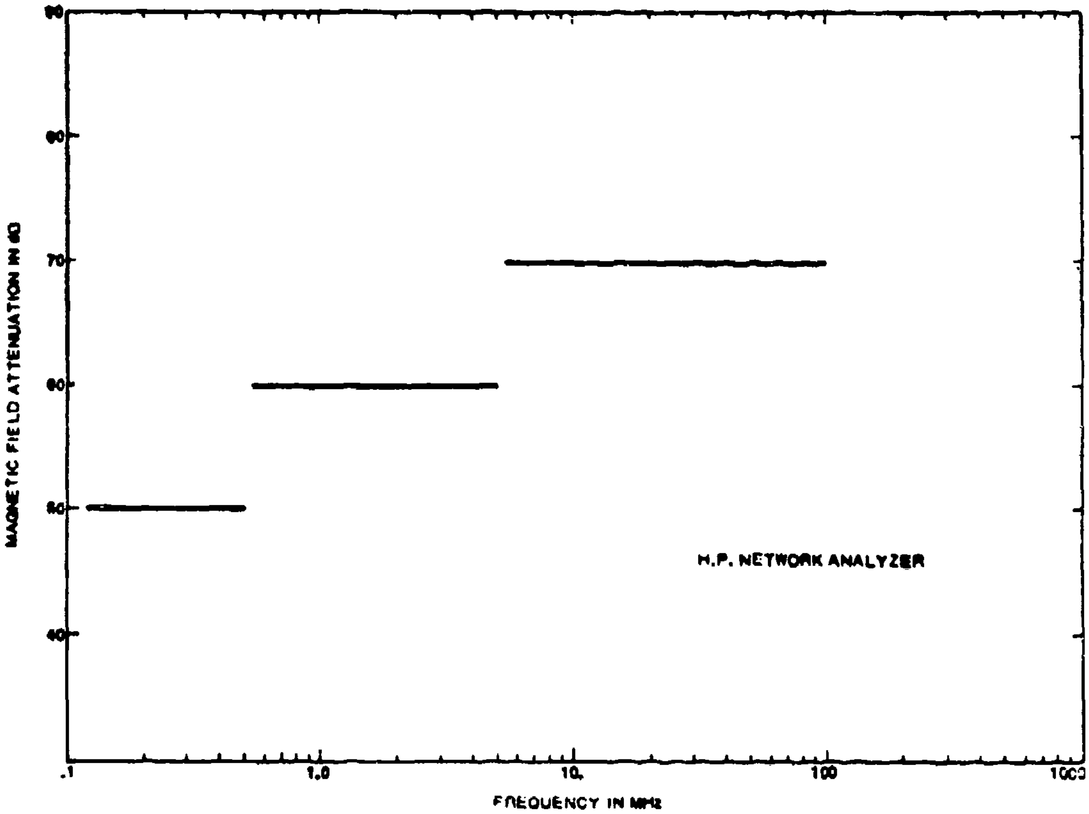


Figure 4. 10. Magnetic Field Attenuation Capability Versus Frequency

$$H_{att}\,(\mathrm{dB}) = 20 \log \frac{H_{inc}}{H_{meas}}$$

H_{inc} = incident magnetic field

H_{meas} = measured magnetic field inside a test object

4.6.4 Cost Estimates

Table 4-7 summarizes the cost estimates for construction and initial checkout of a radiating CW system. Because of the simplicity of the equipment and its easy transportability, all radiating CW systems are considered as temporary facilities.